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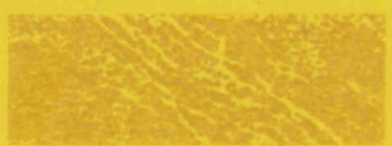

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# F-1A TASK ASSIGNMENT PROGRAM FINAL REPORT

Contract NAS8-18734

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13 ABSTRACT

Design, fabrication, and testing of a single rocket engine having a nominal sea-level thrust rating of 1,800,000 pounds, which could be adjusted and throttled and with features that would reduce usage cost, provide operational simplicity, increased margin of safety, and reduce the number of prelaunch interlocks with the vehicle, as compared to the Qualification II F-1 engine, were the primary goals of the F-1A Task Assignment Program. Design requirements to achieve these goals are given in The F-1A Engine System Design Requirements Specification (Appendix A).

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| Simplified Operational Control System | | | | | | |
| Reduced Interface Requirements | | | | | | |
| Engine Performance/Thrust Versatility | | | | | | |
| Hydraulic Warmant System | | | | | | |
| Turbopump Internal Thrust Control | | | | | | |
| Turbopump Internal Lubrication | | | | | | |
| Elimination of Drain Systems | | | | | | |
| Fluorsilicone Elastomer Seals | | | | | | |
| Improved Start Sequence | | | | | | |
| Gas Generator Hypergol Ignition | | | | | | |
| Turbopump Bearing Warmant | | | | | | |
| Oxidizer Dome Purge Elimination | | | | | | |

## FOREWORD

The F-1A Engine Task Assignment Program effort was performed under Contract NAS8-18734, Change Order 133, G.O. 09070, in compliance with R-7448-2, F-1A Engine and Components Program Plan.

## ABSTRACT

Design, fabrication, and testing of a single rocket engine having a nominal sea-level thrust rating of 1,800,000 pounds, which could be adjusted and throttled and with features that would reduce usage cost, provide operational simplicity, increased margin of safety, and reduce the number of prelaunch interlocks with the vehicle, as compared to the Qualification II F-1 engine, were the primary goals of the F-1A Task Assignment Program. Design requirements to achieve these goals are given in the F-1A Engine System Design Requirements Specification (Appendix A). The design of the F-1A task assignment engine, designated as engine 115-4, would not provide all the features of the final F-1A engine because of limited funding. The differences between the final F-1A engine and the F-1A task assignment engine are given in the F-1A Engine System Design Requirements Specification (Appendix A) and are summarized below. These are:

1. The F-1A task assignment engine would not incorporate a heat exchanger and associated lines. A new heat exchanger system design would be required for the F-1A engine.
2. The F-1A task assignment engine would utilize ethylene glycol as the thrust chamber prefill fluid for engine start. An objective of testing the F-1A task assignment engine would be to evaluate elimination of the thrust chamber prefill fluid for the F-1A engine
3. The F-1A task assignment engine would utilize a LOX dome and gas generator injector operational purge. An objective of testing the F-1A task assignment engine would be to evaluate elimination of the operational purge system for the F-1A engine.
4. The F-1A task assignment engine would not provide gravity drainage for the gas generator combustor. This feature would be designed into the F-1A engine.

5. The F-1A task assignment engine would utilize facility electronic equipment to control the gas generator oxidizer supply throttle valve position. A flight system which would package all the throttle valve position control electronics on the engine could be provided on the F-1A engine.

6. The F-1A task assignment engine would utilize thrust chamber jacket, oxidizer dome, and gas generator oxidizer dome flushing and purging procedures similar to the Qualification II engine. The design of the F-1A engine would simplify servicing of these areas by providing integral flushing system passages into engine hardware such as to require a single servicing connect point for each area.

Design of the components for the F-1A task assignment engine has been completed. Fabrication of hardware for this engine is approximately 40 percent complete.

All new features and operating techniques considered critical were evaluated during supporting component and engine test programs. The results of these test programs are presented in this report. The following features or operating techniques are considered as requiring additional demonstration of feasibility, and could be evaluated during the F-1A Task Assignment Engine Test Program (engine 115-4).

1. Gas generator hypergol ignition
2. Elimination of the LOX dome and gas generator operational purge
3. Elimination of thrust chamber jacket prefill fluid during engine start

The F-1A Task Assignment Program effort has been stopped for an indefinite period. Future reactivation of the program would be based priority and need.

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# INTRODUCTION

The F-1A Task Assignment Program was initiated to study, design, fabricate, and test a rocket engine which would provide reduced usage cost, operational simplicity, greater versatility, increased margin of safety, extended limits capability, and minimization of prelaunch interlocks as compared to the Qualification II F-1 engine. The F-1A engine would be capable of a nominal sea-level thrust rating of 1,800,000 pounds, which could be adjusted between 1,350,000 and 1,800,000 pounds and throttled 300,000 pounds below the calibration rating except as limited by the minimum rating. The scope of work for this effort is presented in the F-1A Engine and Components Program Plan (R-7448-2)

Effort was initiated on 1 April 1968. The first two months were devoted primarily toward studies, analyses, and preliminary design of concepts to provide the desired features. An F-1A Engine System Design Requirements Specification (Appendix A) was prepared, and served as the control document for subsequent design effort. Design, component fabrication, component and engine testing, and assembly of an engine mockup followed. The features of reduced usage cost, operational simplicity, and minimization of prelaunch interlocks were achieved primarily by repackaging the hydraulic control system components, manifolding the hydraulic system lines, use of hydraulic safety interlocks and hydraulic sensing for functional and timing checkout, and incorporating a hypergolic ignition system for the gas generator.

The objective of greater versatility and extended limits capability was achieved by the incorporation of an improved turbopump assembly, which allowed uprating of the nominal sea-level thrust to 1,800,000 pounds and incorporation of a gas generator oxidizer supply throttling control system capable of varying thrust level over the range of 1,350,000 to 1,800,000 pounds.

Figures 1 through 4 are photographs of the completed F-1A engine mockup. A comparison of these photographs with the photographs of the Qualification II engine mockup (Fig. 5 through 8) shows the degree of

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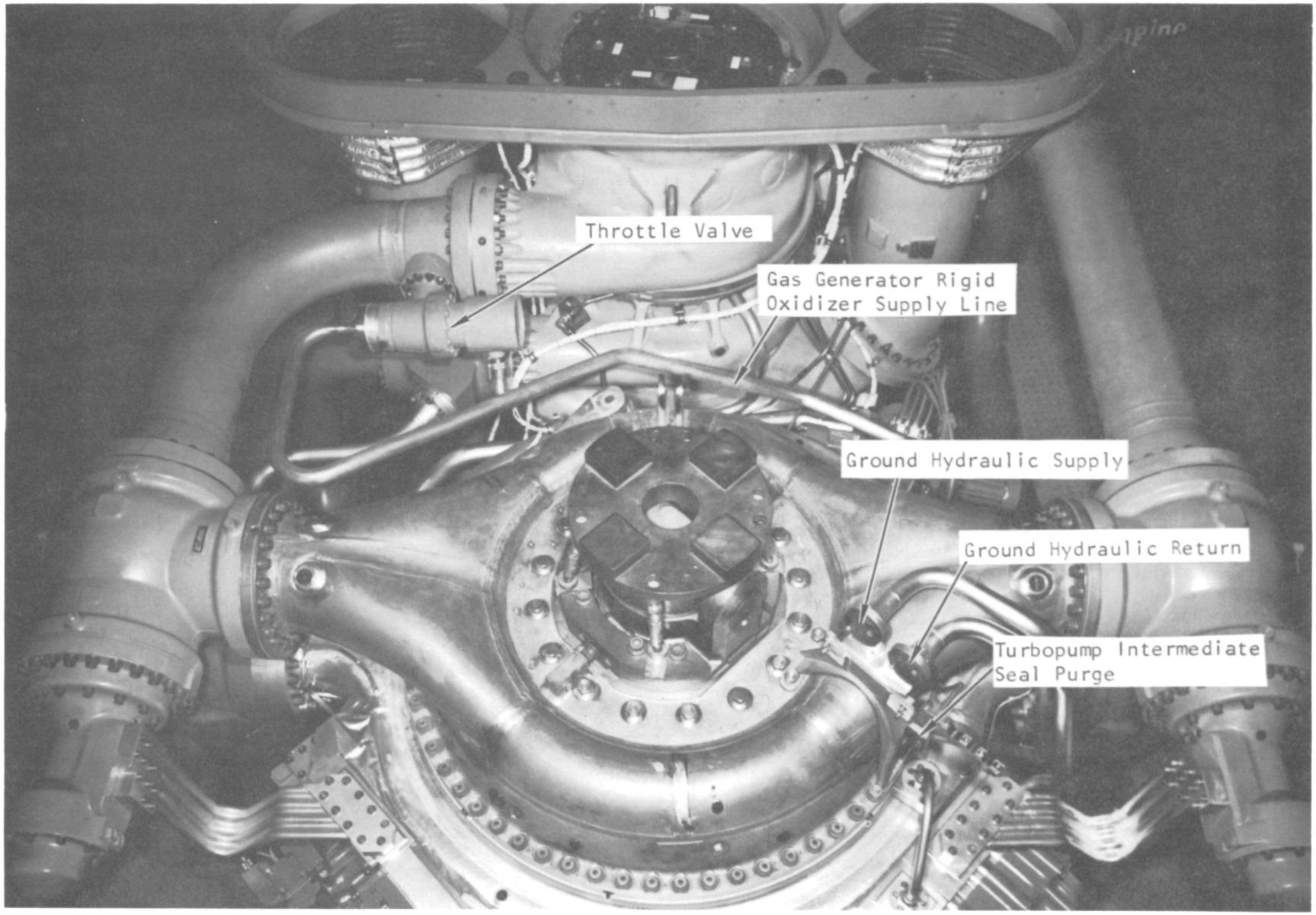


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Figure 1. F-1A Engine Mockup Vehicle Interface

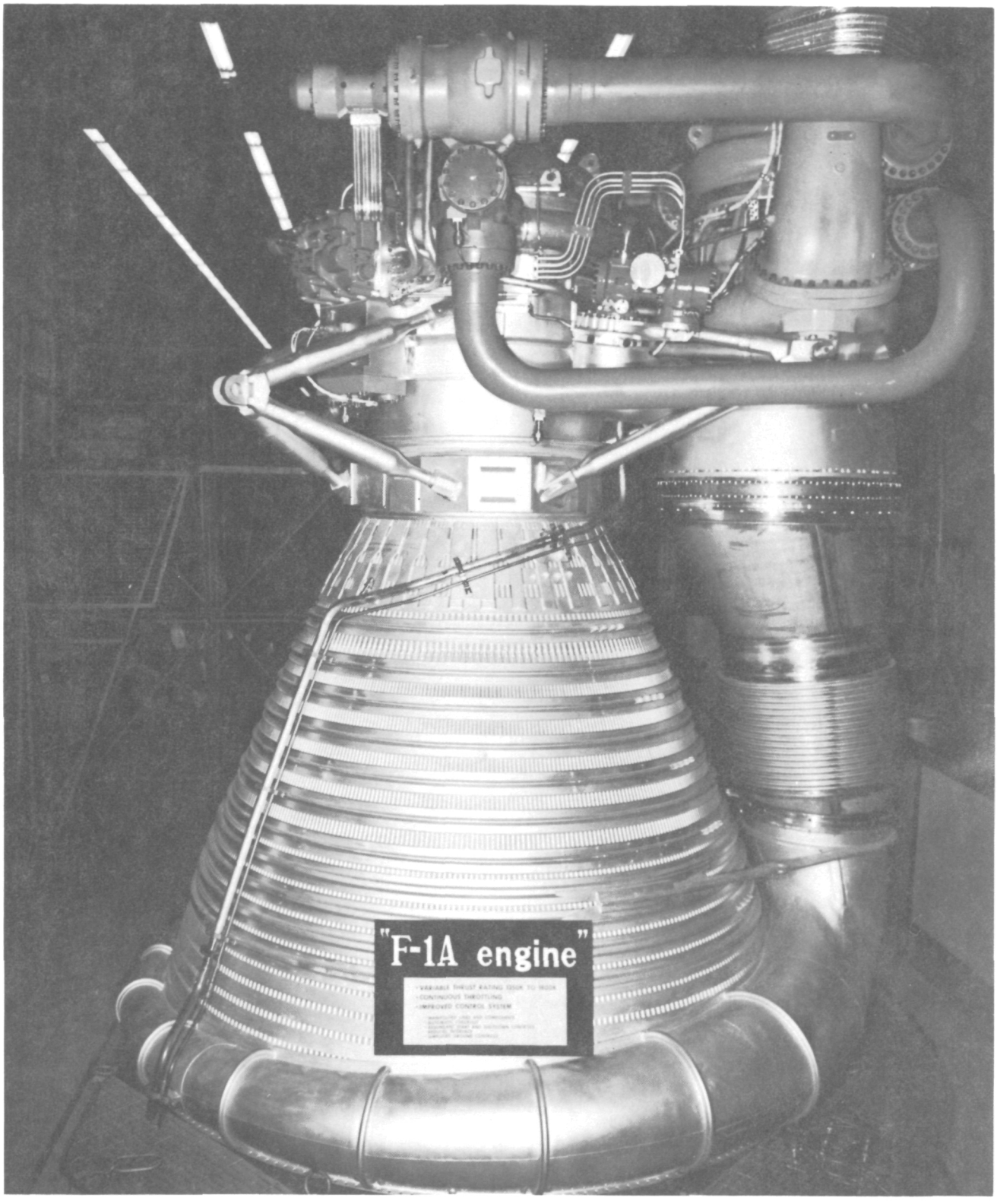


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Figure 2. F-1A Engine Mockup Number 1 Side

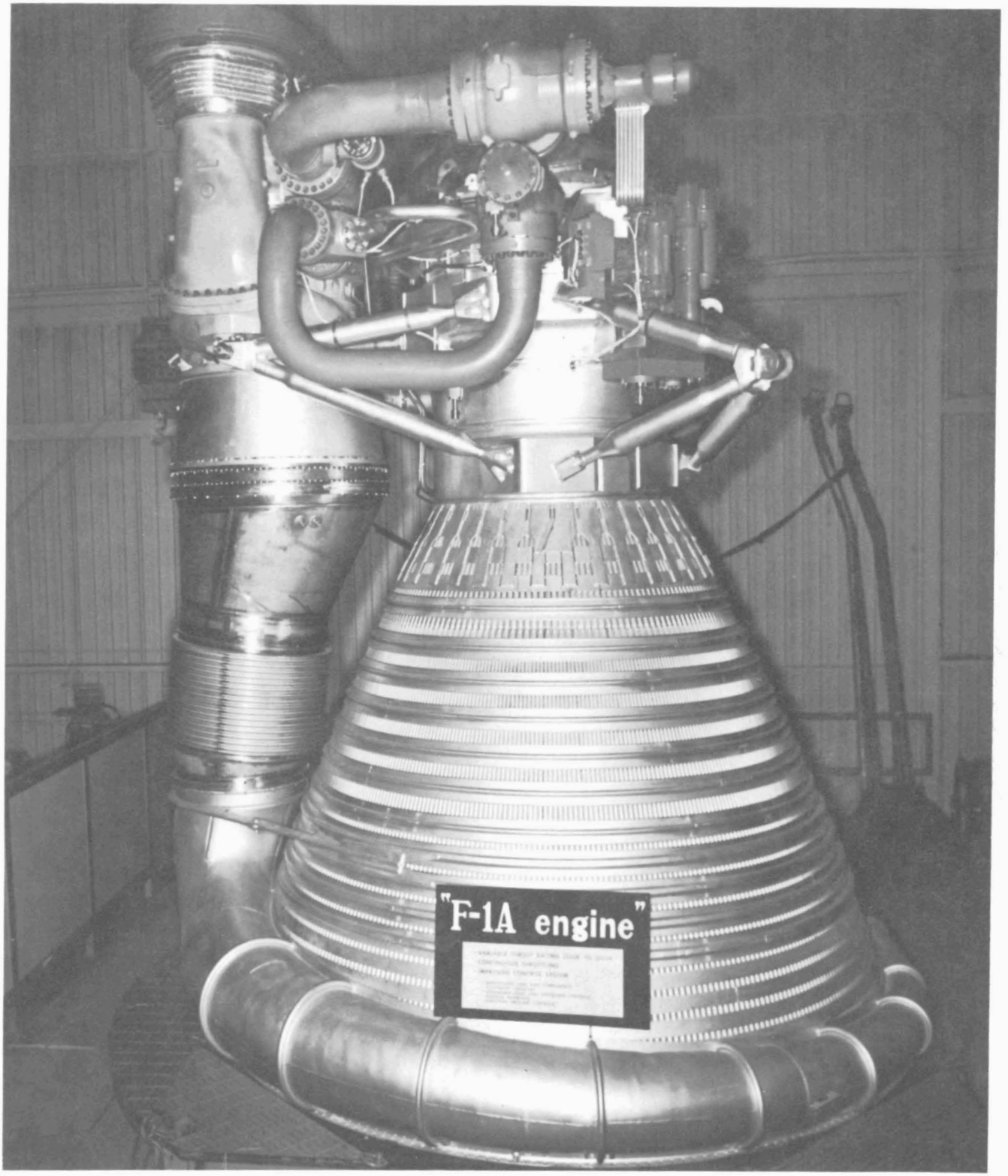


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Figure 3. F-1A Engine Mockup Number 2 Side

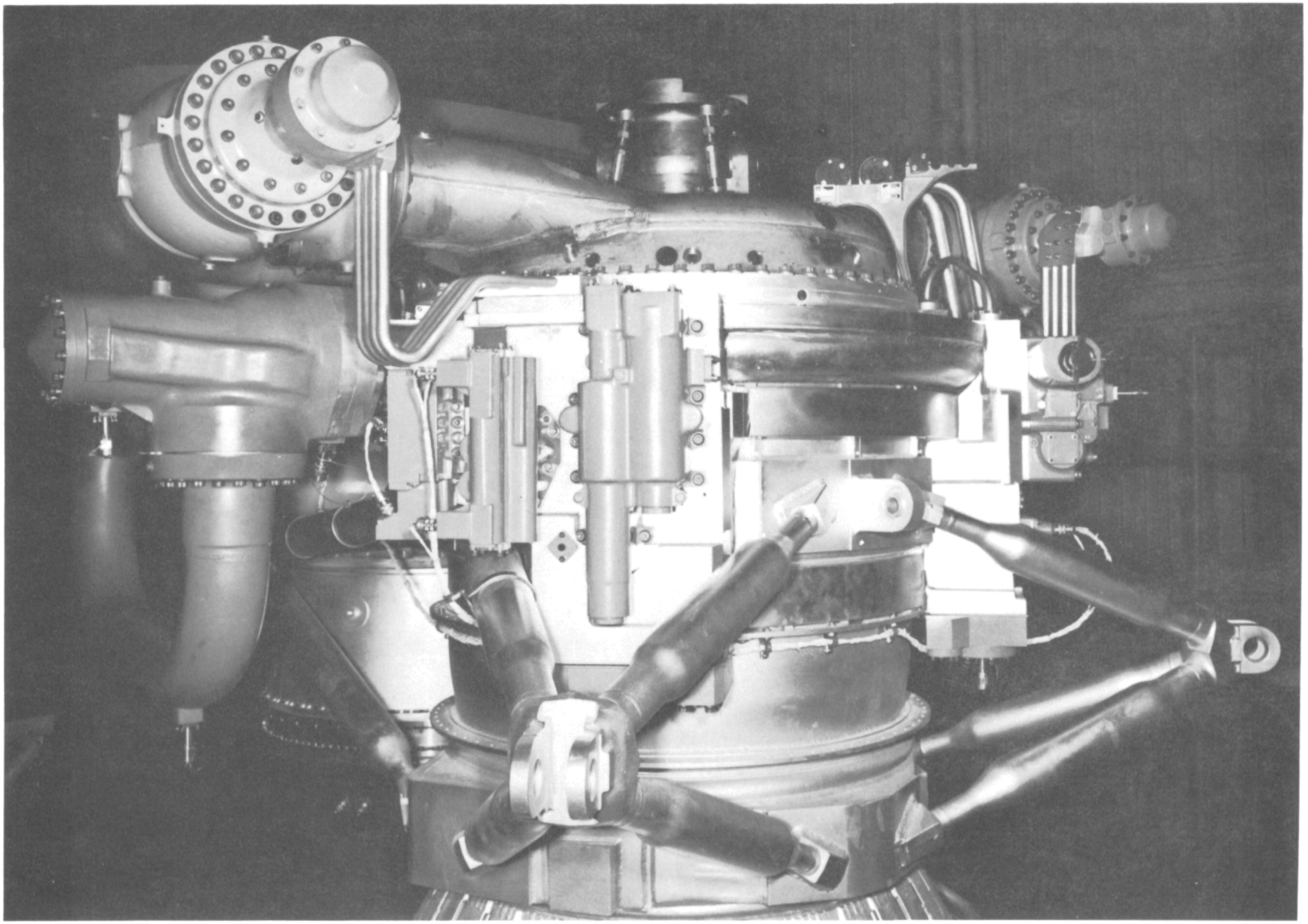

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Figure 4. F-1A Engine Mockup Hydraulic System

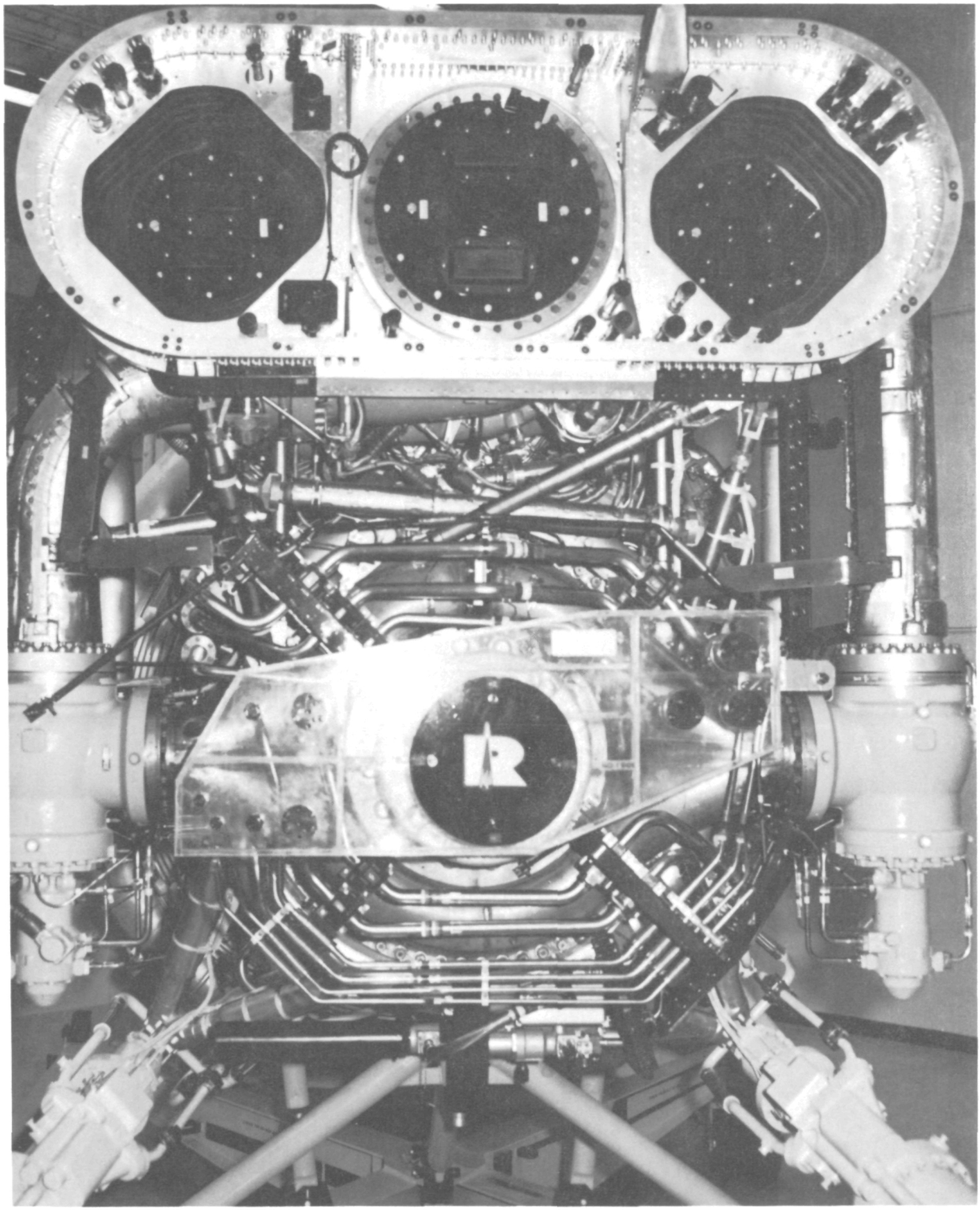

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Figure 5. F-1 Engine Mockup Vehicle Interface

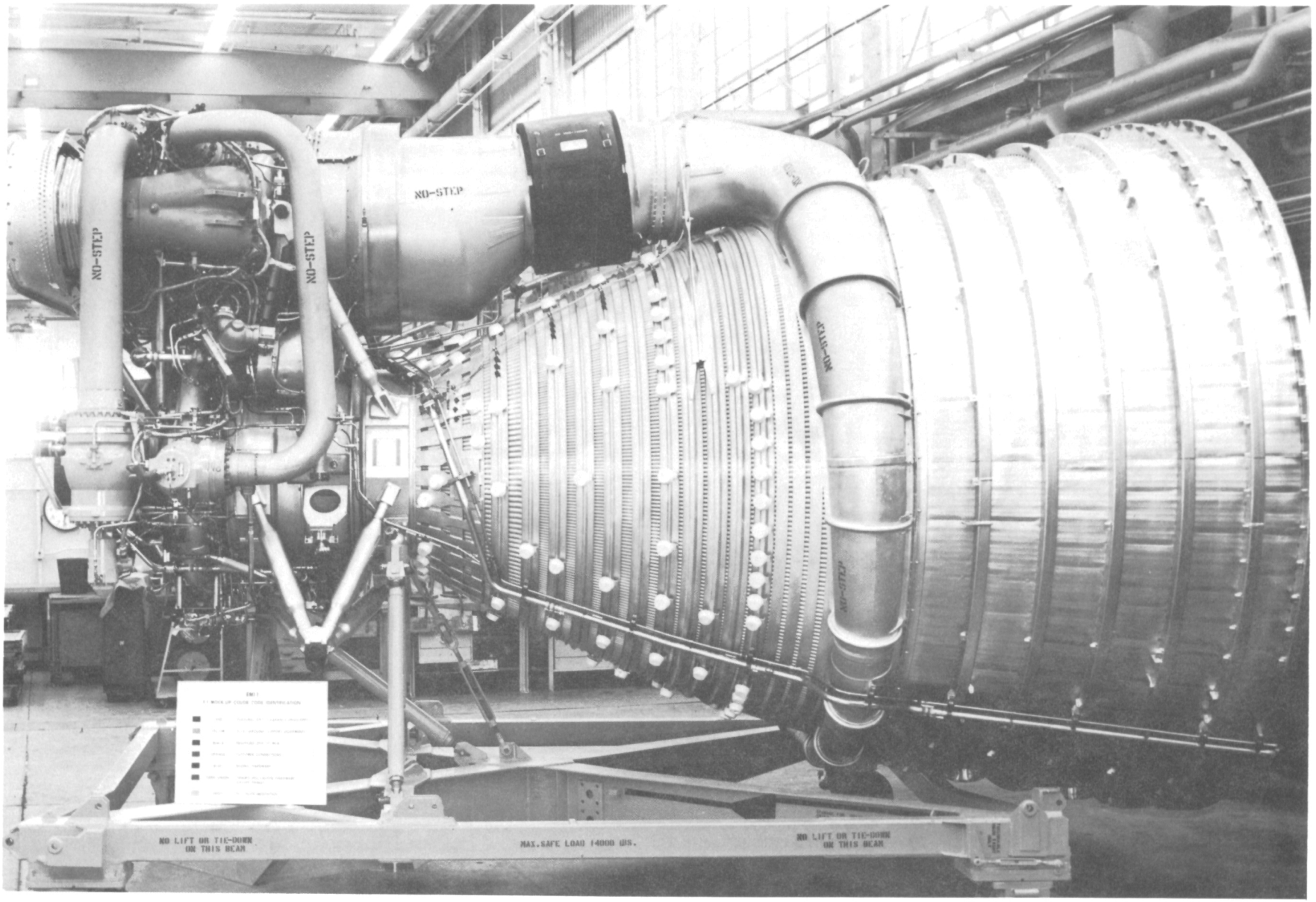


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Figure 6. F-1 Engine Mockup Number 1 Side

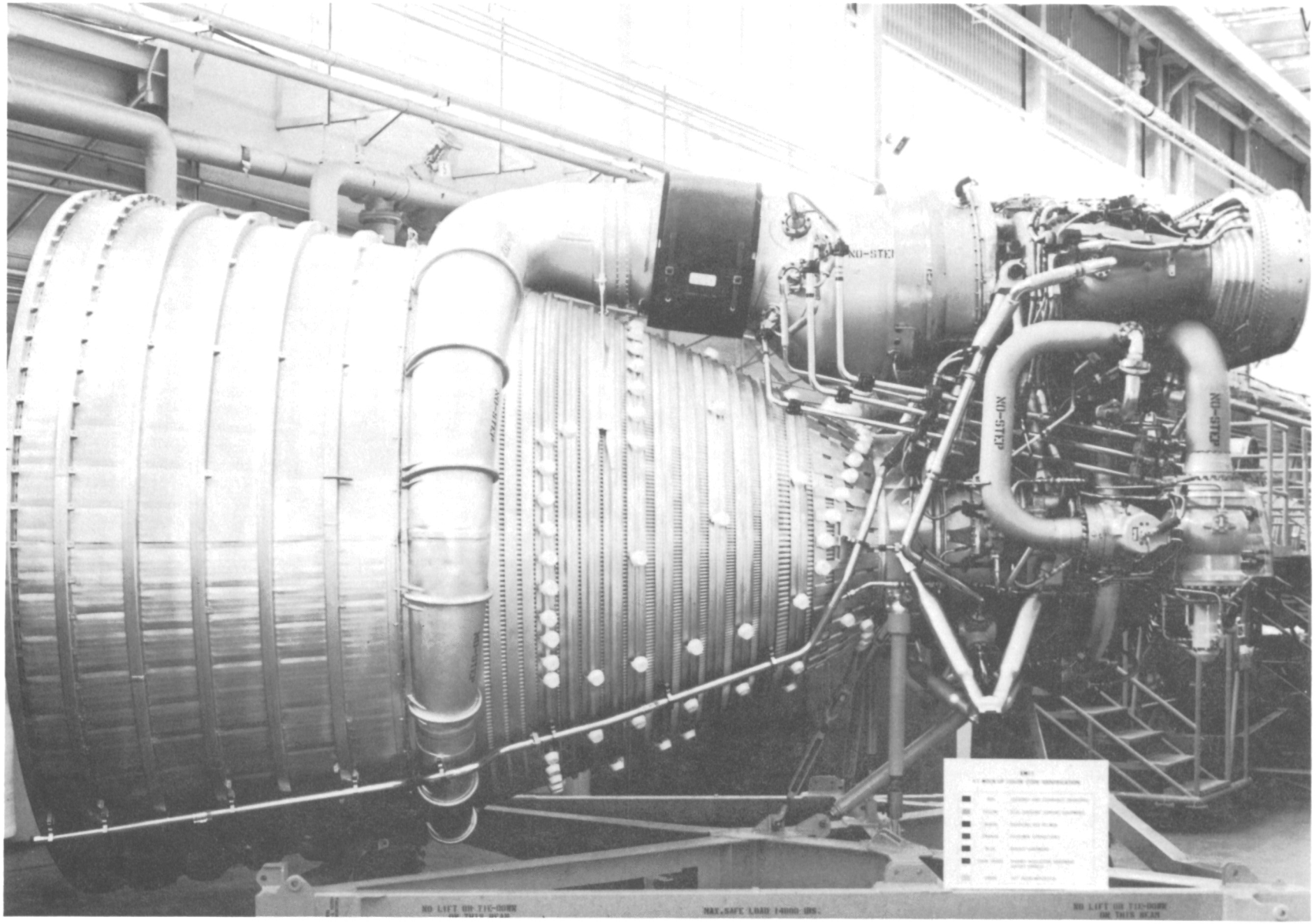

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Figure 7. F-1 Engine Mockup Number 2 Side

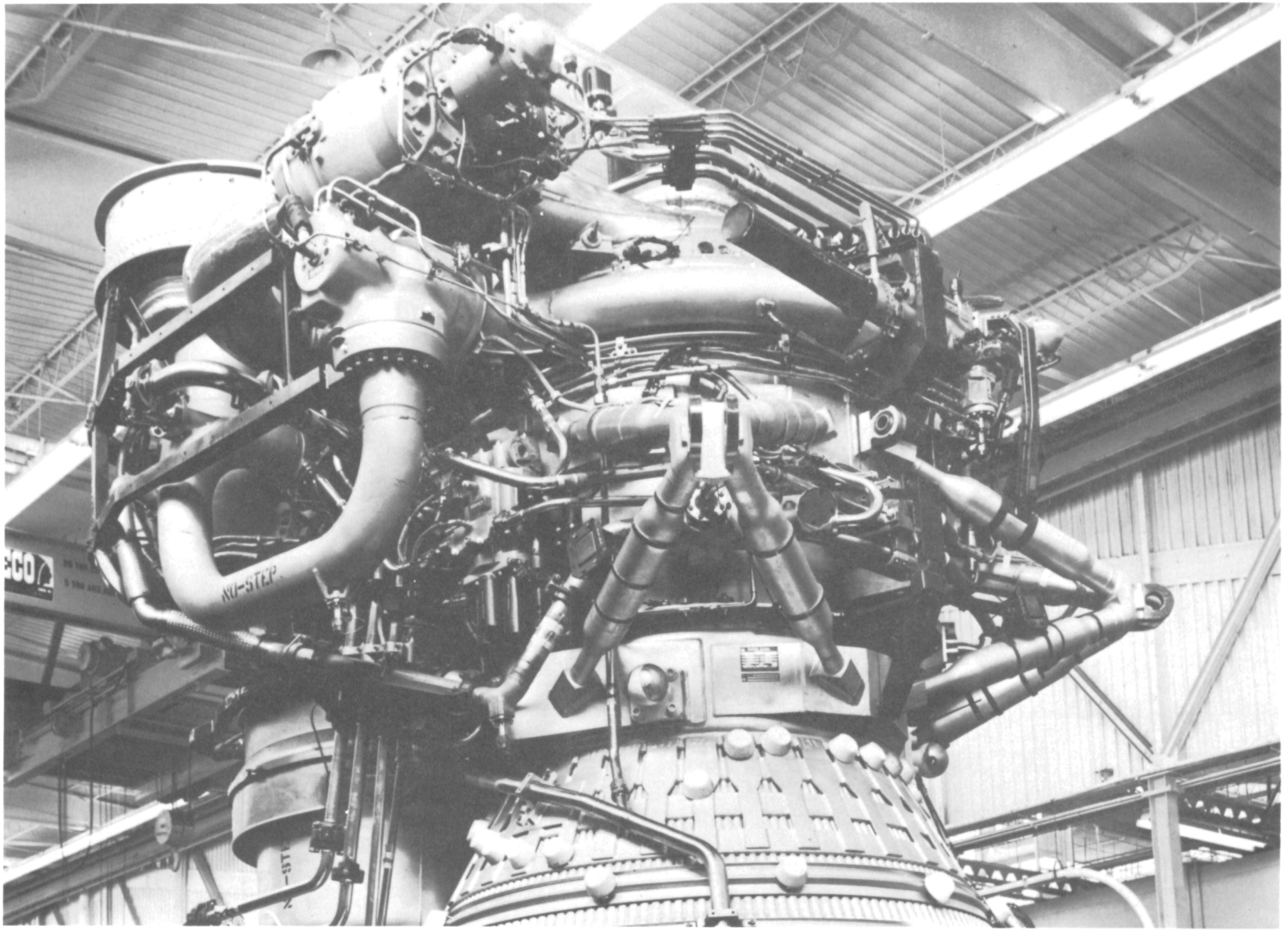

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Figure 8. F-1 Engine Mockup Hydraulic System

physical simplification achieved by repackaging the control system components and manifolding hydraulic lines. A comparison of Fig. 1 and 5 shows the significant interface simplification achieved. The F-1A engine configuration shown in Fig. 1 through 4 is functionally equivalent to the Qualification II engine configuration shown in Fig. 5 through 8, with the exception that the F-1A mockup does not include a pressurization system (heat exchanger), ground hydraulic supply and return wrap-around lines, turbopump intermediate seal wrap-around line, Boeing gimbal actuators, thermal insulation brackets, and a nozzle extension.

Table 1 shows the design and operational simplifications achieved for the F-1A engine system as compared to the Qualification II engine system.

Table 2 shows the reduced interface supply requirements for flight and prelaunch for the F-1A engine system as compared to the Qualification II engine.

The F-1A Task Assignment Program is currently on "Stop" because of priority considerations. This report presents the description and status of the F-1A engine, its components, and its features.

TABLE 1

COMPARISON OF DESIGN AND OPERATIONAL SIMPLIFICATIONS,
QUALIFICATION II ENGINE VS F-1A ENGINE

| Areas of Comparison | Qualification II Engine | F-1A Engine |
|---|---|---|
| Engine Simplifications | | |
| Interfaces | | |
| Stage, Connections and Engine Interconnections | 39 | 21 |
| Servicing Connections | 37 | 24 |
| Instrumentation | | |
| Acceptance | 129 | 8 |
| Flight | 34 | 6 |
| Launch Operations Simplifications | | |
| Propulsion Redlines | 16 | 6 |
| Additional Ground Test Restrictions | 7 | 3 |
| Monitored Countdown Events (Launch Interlocks) | 15 | 2 |

TABLE 2

COMPARISON OF INTERFACE SUPPLY REQUIREMENTS FLIGHT AND PRELAUNCH,
QUALIFICATION II ENGINE VS F-1A ENGINE

| Supply Requirements | Qualification II Engine | | F-1A Engine | | Remarks |
|---|---|---|---|---|---|
| | Flight | Prelaunch | Flight | Prelaunch | |
| Propellant Supply | X | X | X | X | |
| AC Power Requirements | | | | | |
| Heater Power | - | X | - | - | Elimination of all |
| Igniter Power | - | X | - | - | AC power requirements |
| DC Power Requirements | | | | | |
| Checkout Valve Actuation | - | X | - | - | Elimination of DC motor requirements |
| Start Solenoid | - | X | - | X | |
| Stop Solenoid and Override | X | - | X | - | |
| $GN_2$ Pneumatic Supply Requirements | | | | | |
| Turbopump LOX Seal Purge | X | X | X | X | |
| LOX Dome and Gas Generator Operational Purge | - | X | - | - | Elimination of purge |
| Thermal Insulation Cocoon Purge | - | X | - | - | requirements |
| Hydraulic Supply Requirement | | | | | |
| Prestart Engine Hydraulic Control | - | X | - | X | |
| Others | | | | | |
| Thrust Chamber Prefill | - | X | - | - | |
| Control System Checkout | | | | | |
| Pneumatic Supply for IMV Actuation | - | x | - | - | Automatic checkout |
| Pneumatic Supply for Pressure Switch Actuation | - | - | - | - | capability without additional connection |

## DISCUSSION OF F-1A ENGINE FEATURES

Initial effort on the F-1A Task Assignment Program was directed toward studies, analyses, and the preliminary design of concepts to provide the basic objectives of reduced usage cost, operational simplicity, increased margin of safety, extended limits capability, minimization of prelaunch interlocks and greater versatility as compared to the Qualification II type F-1 engine. During this period an engine system design requirements specification (Appendix A) was prepared, and became the control document for subsequent component and system design.

Based on these studies and analysis it was determined that program objectives would best be satisfied by providing the engine with the following features:

1. Simplified operational control system (hydraulic and electrical)
2. Reduced requirements for engine/vehicle interface
3. Engine performance/thrust versatility
4. General system improvements and simplifications

The following is a discussion of the design changes incorporated to provide the engine with the preceding features.

### SIMPLIFIED OPERATIONAL CONTROL SYSTEM (HYDRAULIC AND ELECTRICAL)

The design requirements for the F-1A operational control system are described in Appendix A. Basically simplification was achieved by the following:

1. Repackaging of the system components which housed the control elements of the Qualification II engine control system
2. Manifolding the hydraulic control lines

3. Providing hydraulic sensing of control element functions during checkout to replace a majority of the electrical components provided in the Qualification II engine to perform checkouts

4. Incorporating design changes to improve reliability and provide operational simplicity

Repackaging Control Elements

Repackaging the control elements was accomplished by combining all the sequencing functions performed by the motorized checkout valve, ignition monitor valve, igniter fuel shutoff valve, hypergol container follower mechanical safety interlock, engine control valve, and redundant shutdown valve of the Qualification II engine hydraulic control system into three units. These units are the engine control unit, ignition control unit, and engine arming unit. An additional unit, the sequence instrumentation unit, would perform the sequence checkout functions of the electrical position indicators on the main oxidizer valves, main fuel valves, gas generator valve, checkout valve, and hypergol cartridge follower of the Qualification II engine.

These four units are attached by a single interface to the two hydraulic mounting bases on the thrust chamber body (Fig. 9). The engine arming unit is attached to the No. 1 hydraulic mounting base (Fig. 10) and the engine control unit, ignition control unit and sequence instrumentation unit are attached to the No. 2 hydraulic mounting base (Fig. 11). No hydraulic control lines are attached to the four control system units and their location on the engines allows easy access for servicing replacement (Fig. 9 through 11).

A physical description of each of the control units is given in the Operational Control System section of Appendix A.

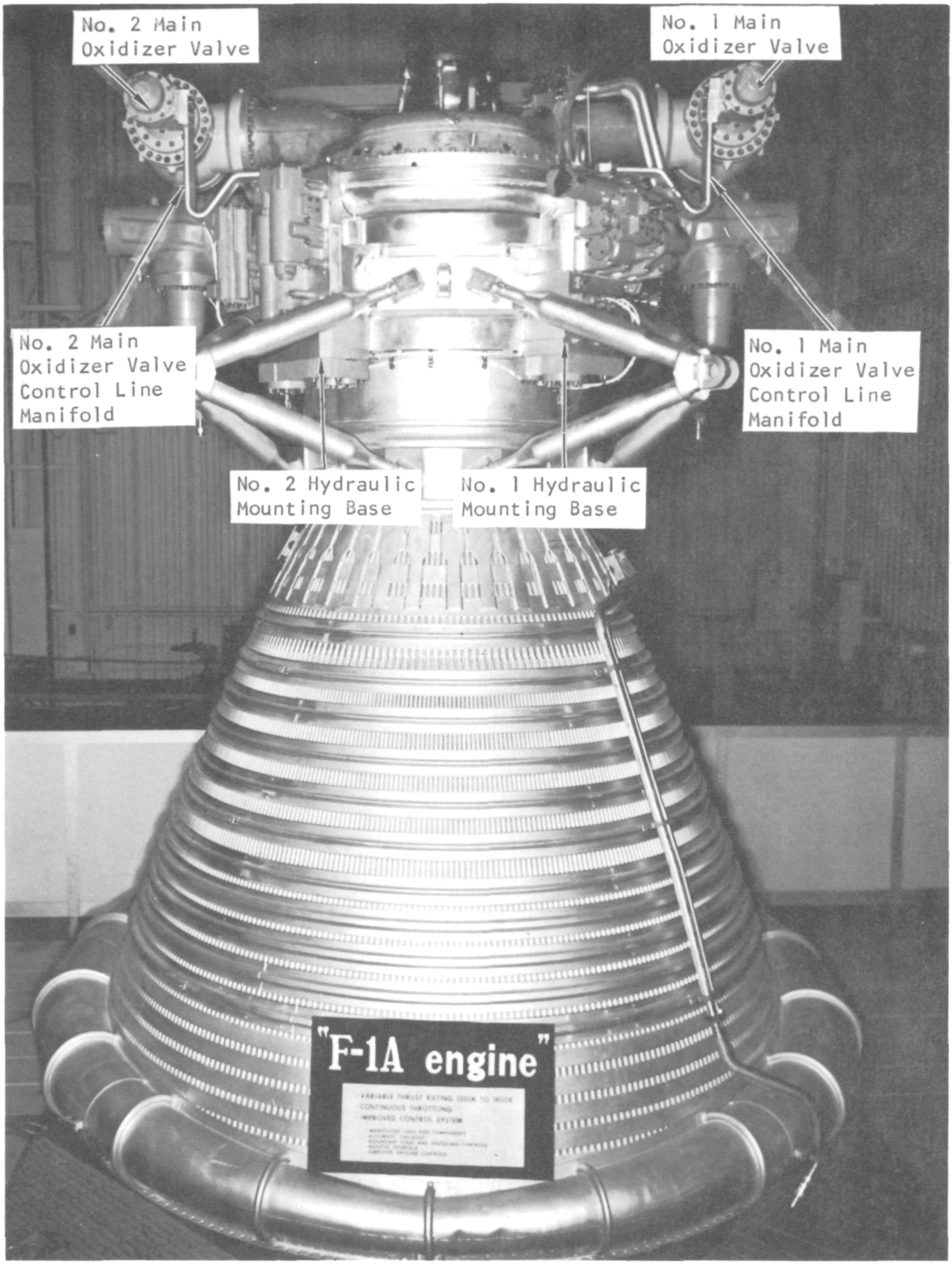


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Figure 9. F-1A Engine Mockup Gimbal Outrigger Side

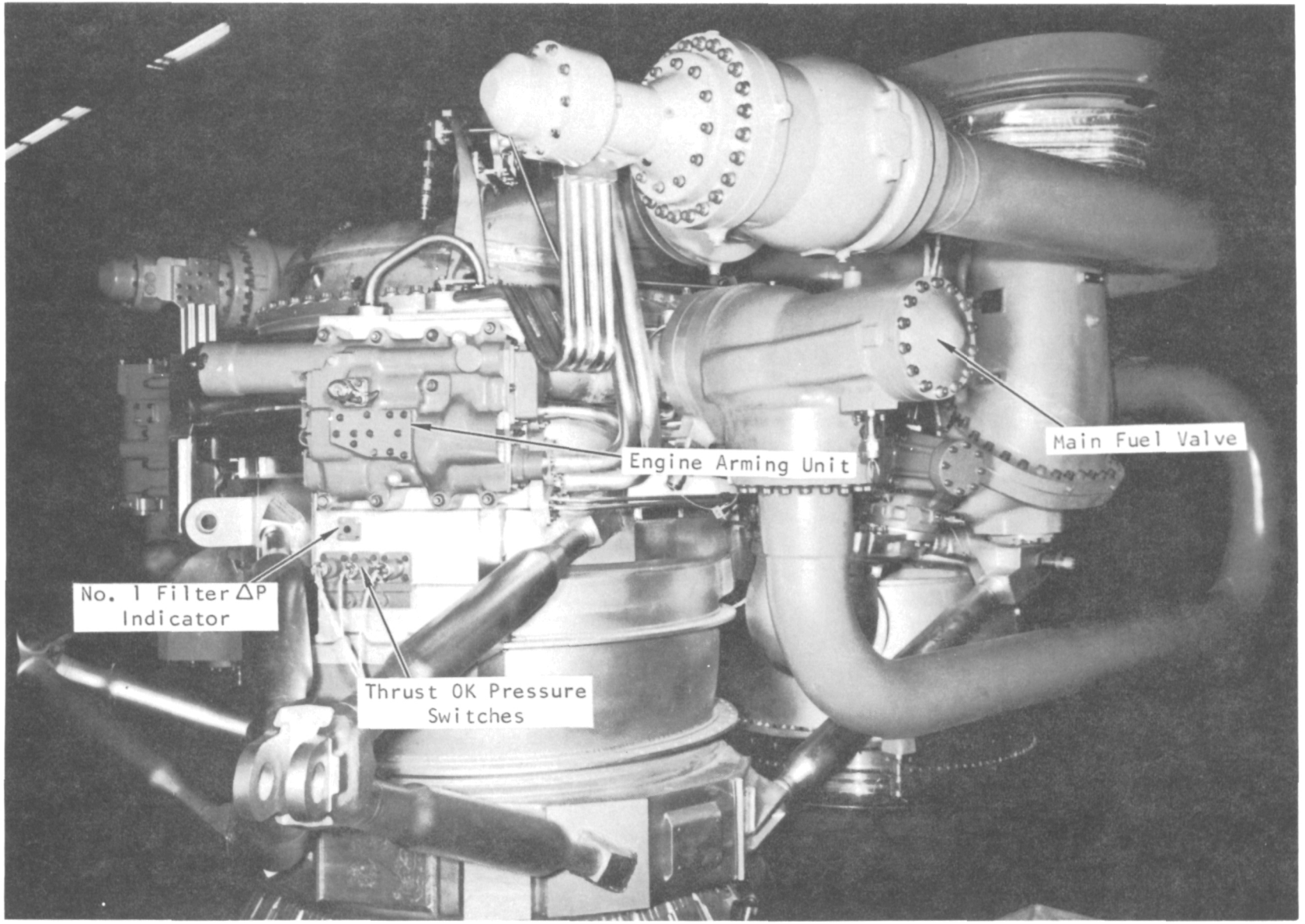


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Figure 10. F-1A Engine Mockup Number 1 Side Components

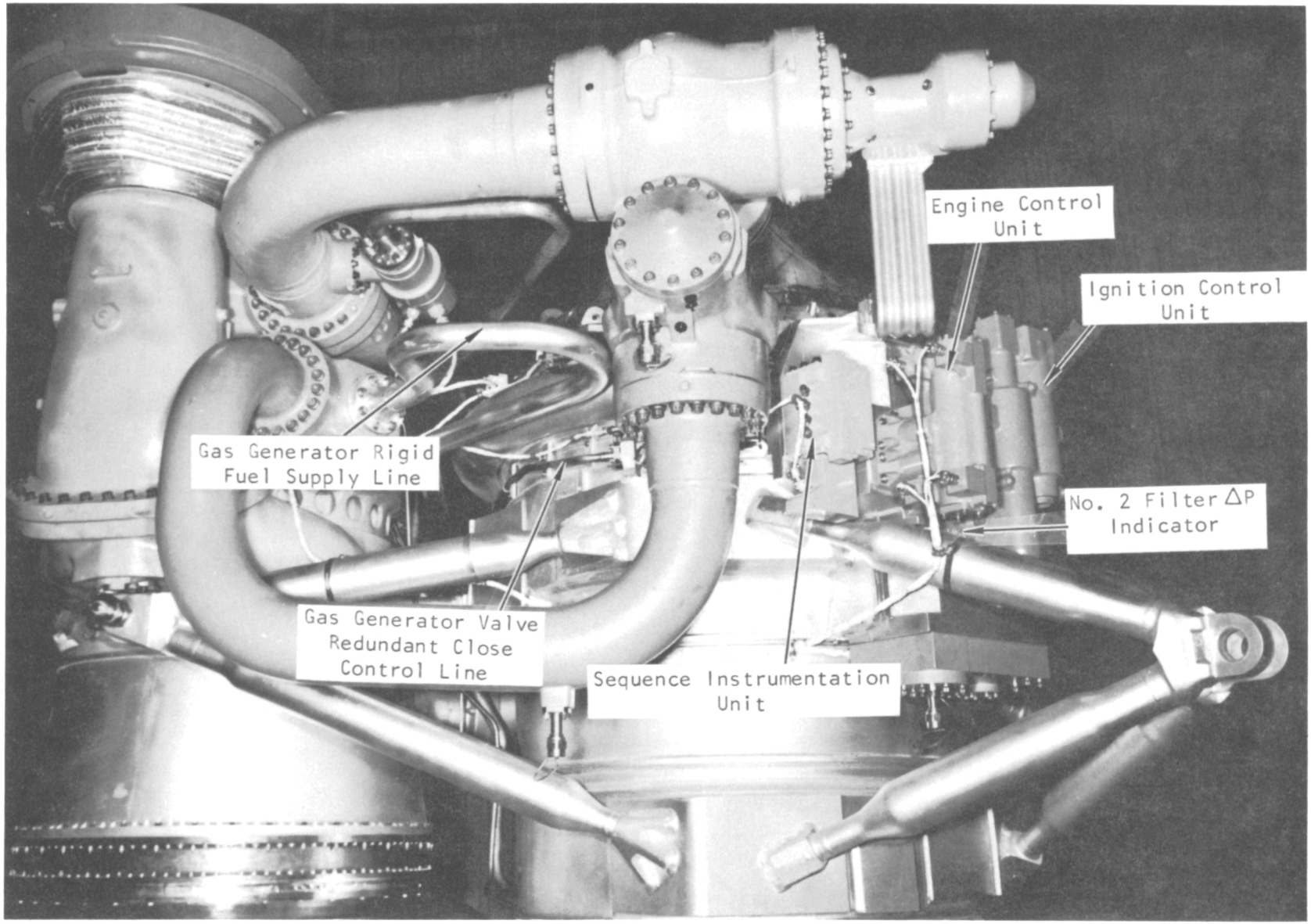


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Figure 11. F-1A Engine Mockup Number 2 Side Components

## Manifolding of Hydraulic Control Lines

A majority of the hydraulic control system fluid passages and lines are incorporated into the hydraulic manifold subassembly. This subassembly consists of the following:

1. The No. 1 and No. 2 hydraulic mounting bases
2. Lines for interconnecting the two hydraulic mounting bases and for directing fluid pressure to various manifold interfaces
3. Two hydraulic system engine supply lines from the two main fuel valves
4. The fluid pressure sense lines from critical control elements
5. Metal shrouds to support and protect the lines

Figure 12 shows this subassembly attached to the thrust chamber body. A schematic of this subassembly is shown in Fig. 13. This subassembly would be assembled and brazed in a jig before weld attachment to the thrust chamber body. There are no joints in the hydraulic lines within the manifold assembly. The four units described previously attach directly to the two hydraulic mounting bases with a single seal plate for each unit (Fig. 10 and 11).

The hydraulic lines which are not housed within the hydraulic manifold subassembly are the following:

1. Hydraulic control and sense lines to each main oxidizer valve (Fig. 9)
2. Control and sense lines to the gas generator valve (Fig. 14)
3. The ground supply line (Fig. 1)
4. The ground return line (Fig. 1)
5. The engine return line (Fig. 14)
6. Gas generator redundant closing control line (Fig. 11)
7. Turbopump warmant supply and return lines

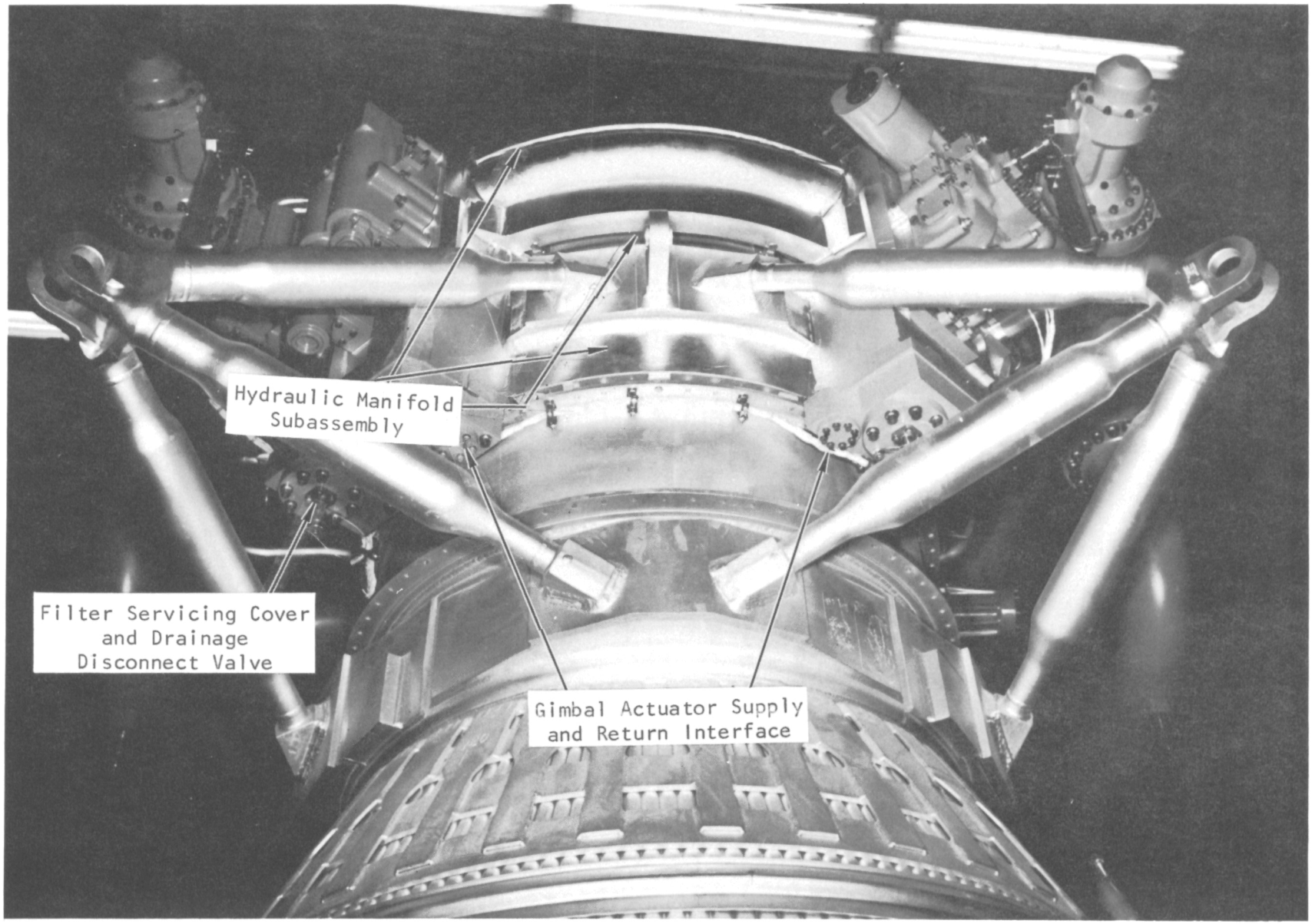


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Figure 12. F-1A Engine Mockup Gimbal Interface

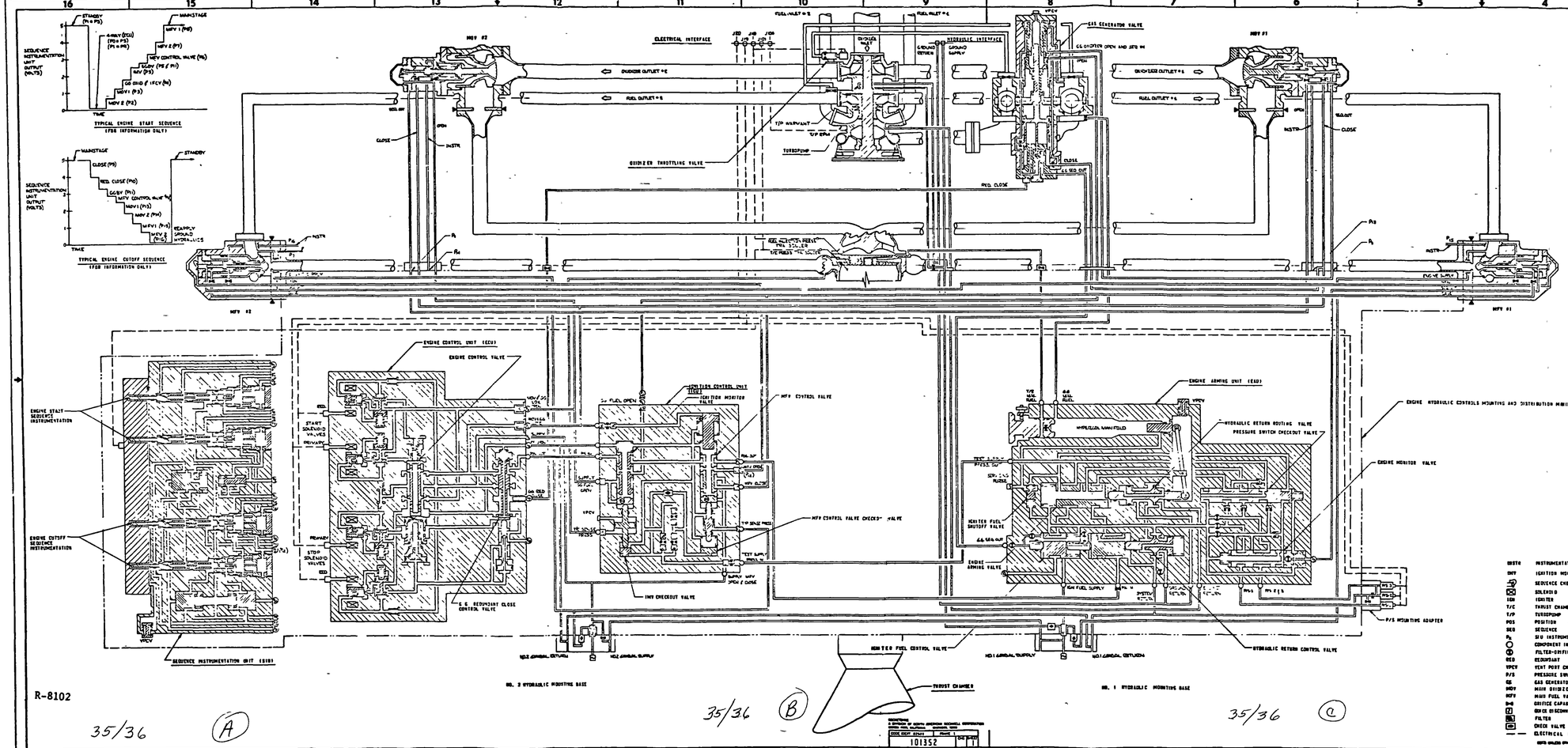


Figure 13. F-1A Engine Control System Schematic (D)

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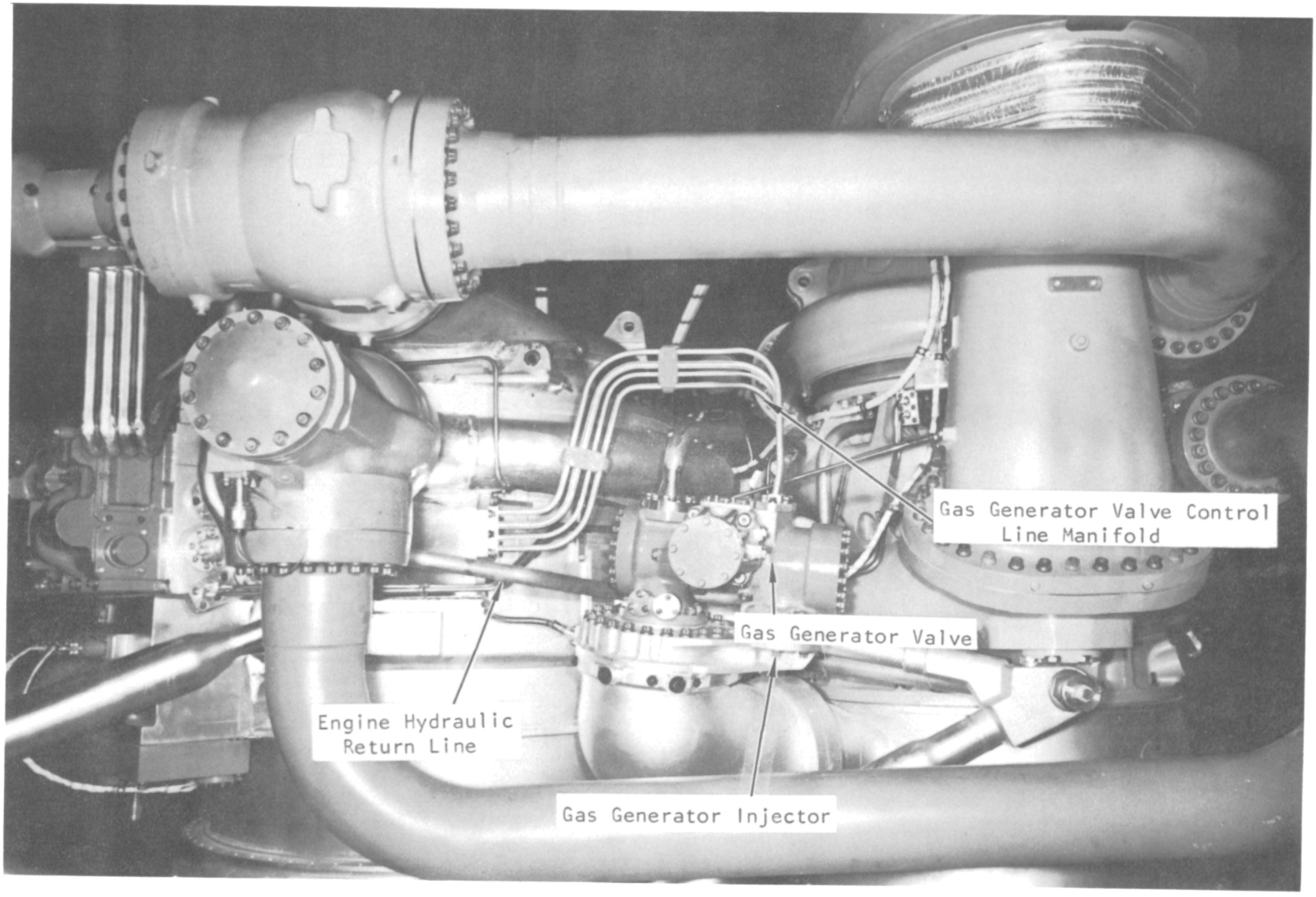


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Figure 14. F-1A Engine Mockup Gas Generator System

These lines have been designed such that they can be installed and replaced without removal of the other components or lines and do not require special adjustment during installation. The lines to the main oxidizer valves and gas generator valve are manifolded assemblies with single end point connect flanges (Fig. 9 and 14). The engine hydraulic return line is designed to be free draining into the fuel pump (Fig. 14).

Hydraulic Sensing of Critical Control Element Functions

Contained within the hydraulic manifold subassembly and the external control line manifolds are fluid passages to sense movement of all the critical hydraulic control elements in the F-1A hydraulic control system. The location of each hydraulic sense point is shown in Fig. 13. These fluid pressures are directed by means of sense lines (part of the hydraulic manifold subassembly) to the No. 2 hydraulic mounting base at the sequence instrumentation unit interface (Fig. 11). A detailed description of the sequence instrumentation unit operation and a listing of the discrete signals provided by the unit together with the timing information obtained is given in Appendix A.

A typical sequence instrumentation unit output trace obtained during engine checkout and for engine start and shutdown is shown in Fig. 13.

Changes to Improve Reliability and Provide Operational Simplicity

Thrust OK Pressure Switches. Three thrust OK pressure switches are provided in the operational control system. These pressure switches are located in the No. 1 hydraulic mounting base (Fig. 10). The pressure switch hydraulic sense circuits and electrical circuits are designed such that the output signals can be utilized to perform multiple functions relative to engine standby condition, operational mode, and performance level indication during flight. These output signals are used to indicate the following:

1. Engine Ready-Checkout Mode: No. 1 pressure switch only is actuated
2. Checkout Sequence Complete Mode: No. 1, 2, and 3 pressure switches are actuated
3. Engine Armed Mode. No. 2 and 3 pressure switches are actuated
4. Launch Commit Mode. Any two of the three pressure switches are actuated
5. Satisfactory engine shutdown following a static test
6. Satisfactory prestart ground-supplied hydraulic pressure

The hydraulic sense circuits required to actuate the switches for each of the preceding modes are shown in Fig. 13. A functional description of the thrust OK pressure switch operation is given in Appendix A. The pressure switches have a fixed setting, however, pressure divider circuits (Fig. 13) are provided in the engine arming unit. These circuits allow adjustment of the pickup pressure so that the pressure is compatible with the engine operating level. The adequacy of individual pressure switch pickup and dropout pressure settings are automatically checked during an engine sequence checkout without the need for an additional external pressure source.

Main Fuel Valves. The main fuel valves for the F-1A engine have no hydraulic lines attached to the valves (Fig.10 ). The hydraulic interface, including the open and close ports, sequence valve outlet port, pressure sensing instrumentation ports, and the engine hydraulic fluid supply port, is provided in the flange which attaches the valve to the thrust chamber. The mating flange on the thrust chamber fuel inlet manifold provides mating porting from the hydraulic manifold subassembly, thus there are no external main fuel valve hydraulic lines. Drilled passages in the main fuel valve body direct hydraulic fluid from the interface to the valve actuator (Fig. 13 ). Valve control orificing is provided within the valve actuator body. These orifices can be identified by visual inspection and can be removed and replaced without removal of any lines.

In addition, the propellant seals on the main fuel valve poppet have been improved. Redundant seals have been incorporated on the poppet skirt and increased loading has been provided on the poppet seal. These seal improvements are designed to eliminate the potential for fuel leakage during engine standby with fuel propellant in the engine and no hydraulic pressure appplied.

Main Oxidizer Valves. The main oxidizer valves for the F-1A engine are provided with a single hydraulic control port interface to allow attachment of the manifolded line assembly described previously (Fig. 9 ). This interface contains the open and close ports, sequence valve outlet port, and pressure sensing instrumentation port. This common interface has been located close to the valve body to reduce the vibration environment at this hydraulic joint. Drilled passages from the hydraulic interface direct hydraulic fluid to the valve actuator (Fig. 13). Valve control orificing is provided within the valve actuator body. These orifices can be identified by visual inspection and can be removed and replaced without removal of any lines.

In addition to the preceding main oxidizer valve hydraulic improvements, a more efficient thermal barrier has been incorporated between the valve body and hydraulic actuator. This change would allow relaxation of the Qualification II engine operational restriction which requires that hydraulic recirculation cannot be stopped for a period greater than 10 minutes with oxidizer propellant in the engine.

Gas Generator Valve. The hydraulic actuator assembly for the F-1A gas generator valve has been designed with the following features:

1. Hydraulic Redundant Closing Actuator: This actuator receives hydraulic pressure from a valve in the engine control unit through a separate line from the normal closing line. The redundant closing actuator is sized such that upon receipt of closing pressure it can close the valve even if hydraulic opening pressure is still applied.

2. Fail-Safe Open Actuator: This actuator receives hydraulic pressure from the fuel propellant side of the valve during operation and provides the piston with a hydraulic lock to keep the valve open in the event of loss of open hydraulic pressure.

3. Actuator Sequencing for Hypergolic Ignition: The actuator assembly has been designed to provide sequenced opening of the oxidizer valve independent of the fuel valve and mechanical linkage between the two valves for simultaneous closing.

4. Common Pad for Hydraulic Control Lines: A common hydraulic control port pad is provided for attachment of the hydraulic line manifold, which contains the open and normal close lines, sequence outlet line, and pressure sensing instrumentation line (Fig. 14). A separate attach pad is provided for attachment of the redundant closing control supply line.

The gas generator valve actuator is shown schematically in Fig. 13 and its operation is described in Appendix A.

The gas generator valve body has been designed with an improved fuel-side hydraulic warmant system. This would allow relaxation of the Qualification II engine operational restrictions which requires that hydraulic recirculation cannot be stopped for a period greater than 10 minutes with oxidizer propellant in the engine. The fuel side of the valve has been designed with an improved interface joint with the injector. This joint would utilize a static seal plate to replace the floating-type joint with O-ring seals utilized on the Qualification II gas generator assembly.

Integrated Gimbal Supply, System Filtration, and Check Valves. Integrated within each hydraulic mounting base are the operational control system supply filters. Each filter is equipped with a pressure differential indicator located on the respective mounting bases (Fig. 10 and 11). These are used to indicate the need for servicing. Filter replacement capability is provided in the gimbal supply manifold at the bottom of each hydraulic mounting base (Fig. 12). Each gimbal supply manifold houses a hydraulic system engine supply check valve. In addition, the No. 1 gimbal manifold houses

the hydraulic system ground supply check valve. The filters and check valves provided in the respective hydraulic mounting bases and gimbal supply manifolds perform the dual function of servicing the hydraulic fluid to the engine hydraulic system and to the gimbal actuators. Gimbal actuator supply and return porting is provided in the gimbal supply manifolds (Fig. 12). This feature eliminates the Boeing gimbal filter manifold and associated ground and engine supply lines. New supply and return lines from the gimbal manifolds to the respective actuators would be required. These features are shown schematically in Fig. 13.

Hydraulic System Operational Features

The following hydraulic system operational features are provided in the F-1A engine.

Preparation Complete Circuit. Engine preparation complete for checkout or for engine start is provided by a series hydraulic fluid monitoring circuit as compared to an electrical circuit in the Qualification II engine. This circuit originates in the engine control unit close port, passes through a land in the gas generator redundant closing control valve in the engine control unit, the ignition monitor valve and main fuel valve control valve in the ignition control unit, the hydraulic return control valve, the engine arming valve, the pressure switch checkout valve, and the engine monitor valve in the engine arming unit, and terminates at the pressure switches on No. 1 hydraulic mounting base. If all the control elements are in the closed position and the ground-supplied hydraulic pressure sensed by the pressure switches is within established limits, an electrical signal is sent across the engine interface to the facility monitor indicating that the operational control system is ready. This circuit can be traced in Fig. 13. During checkout, the preparation complete circuit actuates the No. 1 pressure switch only and during an engine armed mode the preparation complete circuit actuates the No. 2 and 3 pressure switches.

Hypergol Ignition System. The F-1A engine utilizes a single hypergol cartridge to initiate main thrust chamber ignition and gas generator ignition. The ignition system has been integrated into the hydraulic control system

to simplify sequencing and servicing. The hypergol cartridge is installed in the hypergol container in the engine arming unit (Fig. 10). The cartridge is provided with three burst diaphragms, two diaphragms contain the hypergol fluid, and the third provides sequencing control for fluid flow to the thrust chamber injector. During engine start, ground-supplied igniter fuel is sequenced to rupture the two diaphragms which contain the hypergol fluid. As the hypergol fluid flows into the downstream passages (Fig. 13), it is prevented from flowing to the thrust chamber injector by the third diaphragm until the supply line to the gas generator injector is primed.

An orifice is provided in the supply line at the gas generator injector. This acts to suddenly increase the line resistance to hypergol fluid flow. The resulting pressure surge ruptures the third diaphragm, allowing hypergol fluid to flow to the thrust chamber injector. A single servicing disconnect valve is provided on the engine arming unit to purge both the thrust chamber and gas generator igniter fuel flow passages after each test. A servicing tool is installed into the hypergol container for this operation to assure satisfactory purge gas distribution.

Hydraulic System Checkout Test Circuits and Checkout Capability. The hydraulic control system is equipped with special test-only circuits consisting of actuators, hydraulic passages, and pressure divider circuits. These circuits are used to provide engine simulating sequencing for the ignition monitor valve and main fuel valve control valve and for verifying the adequacy of individual pressure switch pickup and dropout pressure settings. The test medium employed for activating these circuits is the same ground-supplied hydraulic fluid used for igniter fuel during engine start. The operating mode for this ground-supplied fluid, that is, checkout mode or armed mode, is determined by the presence or absence of the hypergol cartridge.

The hydraulic actuation of a checkout test circuit causes the actual control system element to move in the same manner in terms of sequence, pressure, and displacement as it would during a normal engine start. The sensing pressures which operate the sequence instrumentation unit during checkout, therefore, are sensing movement of the control element itself and not the test element. The test circuit system together with the sequence instrumentation unit and associated sense passages are designed such that they would not affect control system operation in the event of a failure. A completely remote automatic checkout of the operational control system can be accomplished without any additional connections. The operation of these test circuits is described in Appendix A.

Hydraulic System Multiattitude Drainage. Each gimbal manifold at the bottom of the two hydraulic mounting bases is equipped with a disconnect valve (Fig. 12). These disconnect valves are located such that hydraulic system drainage could be accomplished in any engine attitude. Drainage of the hydraulic system would be accomplished by attaching a drain hose to one of the disconnect valves while applying a gas pressure through the other disconnect valve. When liquid stops draining from the disconnect valve with the drain hose, the disconnect valve functions would be reversed by interchanging the hoses. This alternating means of simultaneously purging and draining the hydraulic system results in complete system drainage without breaking any hydraulic system joints.

Redundancy Provisions. The reliability of the F-1A hydraulic control system has been significantly improved as compared to the Qualification II engine control system by the provisioning of the following redundant features:

Engine Start. Engine start is initiated by the application of electrical d-c power through an interface panel connector to the start solenoid valve in the engine control valve. Complete redundancy is provided for this system. This includes two electrical connectors in the interface panel to receive electrical power, separate routing for the respective harnesses in exposed areas, two start solenoids each with a slave pilot valve in the

engine control unit, and two independent actuating pistons for the engine control valve in the engine control unit.

Engine Shutdown (Normal). Normal engine shutdown is initiated by the application of electrical d-c power through an interface panel connector to the stop solenoid valve in the engine control unit. Complete redundancy is provided for this system. This includes two electrical connectors in the interface panel (the same connectors used for start) to receive electrical power, separate routing for the respective harnesses in exposed areas, two stop solenoids each with a slave pilot valve in the engine control unit, and two independent actuating pistons for the engine control valve in the engine control unit.

Engine Shutdown (Redundant). An alternate engine shutdown system completely independent of the engine control valve is provided on the F-1A engine. This system uses the redundancy provisions for actuating the engine control valve in the engine control unit to actuate a gas generator redundant close control valve also in the engine control unit. This valve is equipped with two actuating pistons, each receiving hydraulic pressure by the operation of the respective stop solenoid. Actuation of this valve directs hydraulic pressure to a redundant gas generator valve closing piston. This piston is completely independent of the gas generator valve normal closing piston and provides redundancy for the gas generator valve normal closing control line by utilizing a completely redundant closing control line and port. The gas generator redundant closing piston is designed such that it could actuate the gas generator valve to the closed position, even if normal open pressure is still applied to the valve actuator. This condition would exist in the unlikely case where the single engine control valve failed to initiate engine shutdown. This system functions during normal engine shutdown.

Engine Hydraulic Supply. Two completely independent engine hydraulic supply systems are provided on the F-1A engine. These systems each originate in the respective main fuel valve, pass through the main fuel valve

to the thrust chamber inlet manifold interface, and then into a passage in the hydraulic manifold subassembly to the respective hydraulic mounting base. Each hydraulic mounting base is equipped with an engine supply check valve and a supply filter. This system, in addition to being redundant, serves the dual functions of supplying hydraulic fluid for the engine control system and to the gimbal actuators during engine operation.

Engine Armed Indication. Engine armed indication for the F-1A engine is provided by the pickup actuation of the No. 2 and/or No. 3 pressure switches. The pickup of these switches is caused by the installation of the hypergol cartridge. With the installation of the cartridge, the No. 1 pressure switch cannot pick up, therefore either switch No. 2 or 3 or both, are capable of indicating the engine armed mode.

Launch Commit Mode. The launch commit mode for the F-1A engine is indicated by the pickup actuation of any two of the three pressure switches. The electrical logic for the three pressure switches is such that pickup signals from two of the switches are sent to each of the two control harness connectors. The failure of one switch, therefore, would still provide a positive launch commit signal.

These redundancy features, including the control harness wiring, are shown in Fig. 13.

## Functional Description of the Operational Control System

A functional description of the operational control system in each of five operating modes which best illustrate system features is presented in Appendix A. These modes are as follows:

1. Checkout Ready-Checkout Mode
2. Checkout Sequence Complete Mode
3. Engine Armed Mode
4. Launch Commit Mode
5. Redundant Shutdown Mode

The engine start and shutdown sequences are also described in Appendix A. Figure 13 is a schematic representation of the operational control system with the control elements shown in a non-operating mode, that is, no hydraulic pressure applied to the system. This drawing should be used to trace the hydraulic and electrical circuits described in Appendix A.

## REDUCED REQUIREMENTS FOR ENGINE/VEHICLE INTERFACE

As a result of design and operational improvements and simplifications incorporated into the F-1A engine, a significant reduction in interface requirements as compared to the Qualification II engine has been accomplished. Tables 1 and 2 present this comparison. This reduction in interface requirements is accomplished by the following:

1. Reducing the number of fluid and mechanical interfaces by eliminating certain servicing and operational fluid requirements and repackaging of control system components.
2. Reducing the number of electrical interfaces by eliminating a majority of electrical launch interlocks, all a-c power requirements, and providing hydraulic actuation for the checkout valve function to replace the electric motor actuator utilized on the Qualification II engine.
3. Reducing the number of flight instrumentation transducers required for performance analysis.
4. Reducing the number of propulsion redline parameters and ground test restrictions
5. Reducing the number of servicing connect points
6. Simplifying engine checkout operations

### Reduced Fluid Interfaces

A comparison of fluid interface requirements for the Qualification II engine vs the F-1A engine is shown in Table 3. Elimination of the LOX

TABLE 3

COMPARISON OF FLUID INTERFACE REQUIREMENTS,
QUALIFICATION II ENGINE VS F-1A ENGINE

| Fluid Interface | Qualification II Engine | F-1A Engine |
|---|---|---|
| Fuel Pump Inlet No. 1 | X | X |
| Fuel Pump Inlet No. 2 | X | X |
| Oxidizer Pump Inlet | X | X |
| Heat Exchanger GOX Return | X | X |
| Heat Exchanger Helium Supply | X | X |
| Heat Exchanger Helium Return | X | X |
| Ground Hydraulic Supply | X | X |
| Ground Hydraulic Return | X | X |
| LOX Dome and Gas Generator Purge | X | - |
| Turbopump LOX Seal Purge | X | X |
| Cocoon Purge | X | - |
| Pressure Switch Checkout Supply | X | - |
| Thrust Chamber Jacket Prefill | X | - |
| Gimbal System Ground Supply | X | - |
| Gimbal System Engine Supply | X | - |
| Gimbal System Actuator Return No. 1 | X | X |
| Gimbal System Actuator Return No. 2 | X | X |
| Gimbal System Actuator Supply No. 1 | - | X |
| Gimbal System Actuator Supply No. 2 | - | X |
| Total | 17 | 13 |

dome and gas generator operational purge and thrust chamber jacket prefill would be based on satisfactory results from an engine test program which could be conducted on the F-1A task assignment engine. The cocoon purge would not be required for the F-1A engine because of the incorporation of seals with improved low-temperature sealing characteristics in the fuel and hydraulic systems. Those seals which utilize fluorosilicone elastomer are discussed in another section of this report.

The pressure switch checkout pneumatic supply requirement is eliminated by the integration of the pressure switches into the operational control system where automatic checkout capability is provided (see section under Thrust OK Pressure Switches). The gimbal system ground and engine supply fluid interfaces are eliminated by integrating the Boeing gimbal filter manifold functions into the repackaged hydraulic control system. The hydraulic control system ground and engine supply lines, associated check valves, and system filters in the repackaged control system are designed to perform the dual function of servicing and supplying fluid to the engine hydraulic system and the gimbal actuators. The No. 1 and 2 gimbal system actuator supply and return fluid interfaces on the F-1A engine are provided in the gimbal manifolds (Fig. 12).

Reduced Electrical Interfaces

A comparison of electrical interface requirements for the Qualification II engine vs the F-1A engine is shown in Table 4. This reduction in electrical interfaces was accomplished by the following:

1. Replacement of the turbopump electrical heater with a hydraulic warmant system, resulting in complete elimination of the 208-vac power requirement.

TABLE 4

COMPARISON OF ELECTRICAL INTERFACE REQUIREMENTS,
QUALIFICATION II ENGINE VS F-1A ENGINE

| Electrical Interface | Qualification II Engine | F-1A Engine |
|---|---|---|
| J18 Electrical Control | X | X |
| J20 Electrical Control | X | X |
| J143 Flight Instrumentation | X | - |
| J140 Flight Instrumentation | X | - |
| J141 Flight Instrumentation | X | - |
| J800 Electrical Control (Heater) | X | - |
| J104 Flight Instrumentation (rpm) | X | X |
| J106 Flight Instrumentation (Temperature) | X | - |
| J100 Flight Instrumentation | X | - |
| J102 Flight Instrumentation | X | - |
| J103 Flight Instrumentation | X | - |
| J101 Flight Instrumentation (Pressure) | X | X |
| J19 Electrical Control | X | - |
| J470 Electrical Control (Igniters) | X | - |
| J58 Turbopump Tachometer | X | - |
| J142 TOPS Switch | X | - |
| J147 TOPS Switch | X | - |
| Total | 17 | 4 |

2. Replacement of the electrically initiated gas generator pyrotechnic igniters with a hypergol ignition system, and elimination of the nozzle extension igniters resulting in complete elimination of the 500-vac power requirement.

3. Reducing the number of flight instrumentation transducers required for performance analysis.

4. Reducing the number of electrical launch interlocks by providing hydraulic interlocks on the engine.

5. Combining all the necessary electrical control functions for the three thrust OK pressure switches, two start solenoids and two stop solenoids into one harness with two interface connectors.

The control harness provided on the F-1A engine is designed such that all critical control functions are routed through redundant wires to the two interface connectors. Each interface electrical connector of this harness provides power for one of the two start solenoids, one of the two stop solenoids, and two of the three pressure switches.

Reduced Electrical Launch Interlocks

A comparison of electrical launch interlocks for the Qualification II engine vs the F-1A engine is shown in Table 5. This reduction in electrical launch interlocks was accomplished by eliminating the electrical position indicators provided on each critical component and the associated electrical harnesses, and providing a hydraulic interlocking and position sensing system which is completely contained within the engine. A description of this system is provided in Appendix A.

Reduced Mechanical Interface

A comparison of mechanical interfaces for the Qualification II engine vs the F-1A engine is shown in Table 6.

TABLE 5

COMPARISON OF LAUNCH INTERLOCKS, QUALIFICATION II ENGINE VS F-1A ENGINE

| Events | Qualification II Engine | F-1A Engine |
|---|---|---|
| No. 1 Main LOX Valve Closed | X | - |
| No. 2 Main LOX Valve Closed | X | - |
| Gas Generator Valve Closed | X | - |
| No. 1 Main Fuel Valve Closed | X | - |
| No. 2 Main Fuel Valve Closed | X | - |
| Gas Generator Igniters, Installed | X | - |
| Turbine Exhaust Igniters, Installed | X | - |
| No. 1 Main Fuel Valve Open | X | - |
| No. 2 Main Fuel Valve Open | X | - |
| Hypergol Installed Switch Dropout | X | - |
| Checkout Valve, Engine Position | X | - |
| Gas Generator Igniter Link Break | X | - |
| Turbine Exhaust Igniter Link Break | X | - |
| Checkout Valve, Ground Position | X | - |
| Preparation Complete (Armed) | - | X |
| Thrust OK | X | X |
| Total | 15 | 2 |

TABLE 6

COMPARISON OF MECHANICAL INTERFACES, QUALIFICATION II ENGINE VS F-1A ENGINE

| Mechanical Interfaces | Qualification II Engine | F-1A Engine |
|---|---|---|
| Gimbal Actuator Mount No. 1 | X | X |
| Gimbal Actuator Mount No. 2 | X | X |
| Heat Shield Curtain (Interface Panel) | X | X |
| Gimbal Filter Manifold Bracket | X | - |
| Gimbal Bearing | X | X |
| Total | 5 | 4 |

Elimination of the gimbal filter manifold bracket was accomplished by integrating the fuctions of the Boeing gimbal filter manifold into the repackaged hydraulic control system (see section on Integrated Gimbal Supply, System Filtration, and Check Valves).

Reduced Flight Instrumentation

A total of six flight instrumentation parameters is required for the F-1A engine as compared to 34 for the Qualification II engine. These are:

1. Main chamber combustion pressure
2. Turbopump rpm
3. Sequence instrumentation unit output signal
4. No. 1 pressure switch output
5. No. 2 pressure switch output
6. No. 3 pressure switch output

The reduction in electrical interface requirements achieved by this change is shown in Table 4. Main chamber combustion pressure and turbopump rpm are required for flight performance analysis; sequence instrumentation unit output is required for sequence event monitoring and timing; and output signals from the three pressure switches are required to indicate engine standby mode, thrust OK for launch, and as an inflight indication of satisfactory engine thrust. These six signals are transmitted through a simplified interface panel by the four interface electrical connectors.

Reduced Propulsion Redlines and
Ground Test Restrictions

A comparison of the propulsion redlines and ground test restrictions for the Qualification II engine vs the F-1A engine is shown in Table 7. The elimination of the redline parameters as indicated on Table 7 has been accomplished in the following manner.

1. The control system minimum ground supply pressure redline is eliminated by the function of the thrust OK pressure switches which provide automatic indication that the hydraulic pressure is within the acceptable limit for engine start. The control system maximum ground supply pressure redline is eliminated because the F-1A engine is designed to operate satisfactorily within the ground hydraulic supply facility limitation (relief setting).
2. The control system fluid temperature limits are relaxed by incorporation of improved hydraulic warmant systems in cryogenic components.
3. The engine environment temperature limits are eliminated by incorporation of seals with improved low-temperature sealing characteristics in the fuel and hydraulic systems.
4. The LOX pump seal cavity pressure limit is eliminated and replaced by a requirement to visually monitor the LOX overboard drain line for evidence of LOX leakage after LOX is introduced into the engine.

TABLE 7

COMPARISON OF PROPULSION REDLINES AND GROUND TEST RESTRICTIONS, QUALIFICATION II ENGINE VS F-1A ENGINE

| Engine Limits | Qualification II Engine | F-1A Engine |
|---|---|---|
| Restart or Launch | | |
| Control System Maximum-Minimum Pressure | XX | - |
| LOX Pump Inlet Minimum Temperature | X | X |
| LOX Pump Seal Purge Minimum Maximum Pressure | XX | X |
| Fuel Pump Inlet Minimum Pressure | X | X |
| LOX Pump Inlet Minimum Pressure | X | X |
| Control System Fluid Minimum Maximum Temperature | XX | Relaxed |
| Engine Environmental Minimum Maximum Temperature | XX | - |
| LOX Pump Seal Cavity Maximum Pressure | X | - |
| No. 1 Bearing Minimum Maximum Temperature | XX | - |
| DC Minimum Maximum Voltage | XX | XX |
| Total | 16 | 6 |
| Ground Test Operating Restrictions | | |
| Fuel Impeller Backcasing Maximum Minimum Pressure | XX | - |
| Fuel Pump Discharge Maximum Pressure | X | X |
| LOX Pump Discharge Maximum Pressure | X | X |
| Turbopump Bearing Jet Maximum Minimum Pressure | XX | - |
| Turbine Inlet Maximum Temperature | X | X |
| Total | 7 | 3 |

5. The No. 1 bearing temperature limits are eliminated by the incorporation of the hydraulic fluid bearing warmant system. When the thrust OK pressure switches are picked up prior to introducing oxidizer propellant into the engine, assurance is provided that warmant flow is established in the bearing warmant system.

6. The fuel impeller backcasing pressure limits are eliminated by incorporation of the turbopump internal axial thrust control system.

7. The turbopump bearing jet lubrication pressure limits are eliminated by incorporation of the turbopump bearing internal lubrication system.

8. The LOX pump seal purge maximum pressure redline is eliminated by incorporation of an improved turbopump intermediate seal.

Reduced Servicing Interfaces

A comparison of servicing interfaces for the Qualification II engine vs the F-1A engine is shown in Table 8. The reduction in servicing interfaces is accomplished by the following:

1. Incorporation of the internal bearing lubrication system, which eliminated two drainage disconnect valves.

2. Repackaging of the hydraulic control system provided self draining in the ignition monitor valve sense line, hydraulic return line, and gimbal return line. Incorporation of the hypergol manifold into the hydraulic system allowed elimination of the hypergol manifold drain. This change allowed elimination of four drainage disconnect valves.

3. Elimination of the gas generator combustor body drain would be accomplished on the F-1A engine by designing the hardware to be self draining.

4. Elimination of the No. 1 and No. 2 gas generator fuel service purge is accomplished by incorporation of a solvent-compatible seal in the joint between the gas generator fuel valve and injector.

TABLE 8

COMPARISON OF SERVICING INTERFACES, QUALIFICATION II ENGINE VS F-1A ENGINE

| Servicing Interfaces | Qualification II Engine | F-1A Engine |
|---|---|---|
| Drain Ports | | |
| No. 1 Fuel High-Pressure Duct Drain | X | X |
| No. 2 Fuel High-Pressure Duct Drain | X | X |
| No. 1 Thrust Chamber Fuel Manifold Inlet Drain | X | X |
| No. 2 Thrust Chamber Fuel Manifold Inlet Drain | X | X |
| No. 1 Fuel Pump Inlet Drain | X | - |
| No. 2 Fuel Pump Inlet Drain | X | - |
| Turbine Bearing Drain | X | X |
| Hypergol Manifold Drain | X | - |
| Ignition Monitor Valve Drain | X | - |
| Hydraulic Return Line Drain | X | - |
| Gimbal Return Line Drain | X | - |
| Engine Hydraulic Supply Line Drain | X | - |
| Thrust Chamber Return Manifold Drains (4) | XXXX | XXXX |
| Gas Generator Combustor Drain | X | - |
| Gas Generator Valve Fuel Inlet Drain | X | X |
| No. 1 Hydraulic System Drain | - | X |
| No. 2 Hydraulic System Drain | - | X |
| Purge Ports | | |
| No. 1 Main Fuel Valve Purge | X | X |
| No. 2 Main Fuel Valve Purge | X | X |
| Bearing Coolant Valve Purge | X | - |
| Hypergol Manifold Purge | X | X |
| No. 1 Gas Generator Fuel Service Purge | X | - |
| No. 2 Gas Generator Fuel Service Purge | X | - |
| LOX Dome-Gas Generator Service Purge | X | - |
| Turbopump Intermediate Seal Purge | X | X |

TABLE 8

(Concluded)

| Servicing Interfaces | Qualification II Engine | F-1A Engine |
|---|---|---|
| Flush Ports | | |
| No. 1 Thrust Chamber Fuel Inlet Manifold Flush | X | - |
| No. 2 Thrust Chamber Fuel Inlet Manifold Flush | X | - |
| LOX Dome Flush (6) | XXXXXX | - |
| Gas Generator LOX Flush | X | X |
| Thrust Chamber Fuel System Flush | - | XX |
| Thrust Chamber Oxidizer System Flush | - | X |
| Gas Generator Fuel System Flush | - | X |
| Miscellaneous | | |
| Turbopump Torque Gear | X | X |
| Turbopump Preservative Port | X | XX |
| Total | 37 | 24 |

5. The LOX dome and gas generator servicing purge and the six LOX dome flush ports are eliminated, and their function would be performed by a single thrust chamber oxidizer system flush port on the F-1A engine. A single port would be provided on the gas generator valve for flushing and purging the injector oxidizer dome.

6. The No. 1 and No. 2 thrust chamber fuel inlet manifold flush ports would be eliminated, and their function accomplished by a flush and purge port in each main fuel valve.

7. The gas generator fuel flush port is an added requirement for servicing the fuel injector with gas generator hypergol ignition.

## ENGINE PERFORMANCE/THRUST VERSATILITY

The F-1A engine is capable of a nominal sea-level thrust rating of 1,800,000 pounds which could be adjusted between 1,350,000 and 1,800,000 pounds and throttled 300,000 pounds below the calibration rating except as limited by the minimum rating. This capability was accomplished by the incorporation of the 30-inch turbine turbopump and a thrust control system.

### Thirty-Inch Turbine Turbopump

Incorporation of the 30-inch turbine turbopump provides the F-1A engine with the capability of uprating to 1,800,000 pounds thrust with an adequate structural margin of safety relative to all pump components. This pump is equipped with the following features to improve performance or increased margin of safety:

1. The oxidizer and fuel pump impellers are changed from a six-vane configuration made of nominal Tens-50T60 aluminum alloy to a 6+6 vane (six full and six partial vanes) configuration made of high-strength, premium grade, Tens-50T60 aluminum alloy. This change, in addition to providing improved head flow performance characteristics, reduced the turbopump operating speed, which provides the capability for uprating. This change also reduced pump discharge pressure oscillations during operation, resulting in an improved engine vibration environment.
2. The oxidizer and fuel pump inducers were changed to provide the 30-inch turbine turbopump with improved net positive suction head performance characteristics. The oxidizer inducer was increased in diameter and the fuel inducer was changed from a tapered to a cylindrical configuration. The material of the fuel inducer was changed from 7075 aluminum alloy to titanium for improved structural characteristics.

3 The turbopump shaft was redesigned to increase its stiffness (SMID shaft). This change increased the turbopump critical speed, allowing relaxation of the allowable operating speed limit which provided greater flexibility relative to uprating.

4. The turbine was redesigned to provide a greater nozzle area, which allowed operation at the increased hot-gas flowrate required for 1,800,000-pound-thrust operation with a satisfactory margin of safety relative to turbine inlet manifold temperature and pressure limits.

A comparison of developed head vs flow for the Qualification II engine and the F-1A engine oxidizer and fuel pumps is given in Fig. 15.

Thrust Control System

The thrust control system is an optional feature on the F-1A engine. Incorporation of the thrust control system allows throttling of engine thrust in the range of 1,350,000 to 1,800,000 pounds. The design requirements for this system are described in the F-1A Engine System Design Requirements Specification (Appendix A). This system could be designed to be completely contained on the engine or a portion of the electronic controls provided by the stage. The closed-loop feed-back signal for this system would be provided by a transducer monitoring thrust chamber fuel injection pressure. Variation of specific impulse and engine mixture ratio as a result of throttling gas generator oxidizer flow to change engine thrust are shown in Fig. 16 and 17, respectively. In addition to providing the F-1A engine with thrust versatility relative to vehicle application, the thrust control system provides a simplified means for thrust calibration. The thrust control system also allows maximum utilization of vehicle design for any set of vehicle structural constraints. By optimizing the flight thrust profile for these structural constraints, which usually result from liftoff transients, aerodynamic loading, and vehicle acceleration, maximum payload capability would be achieved.

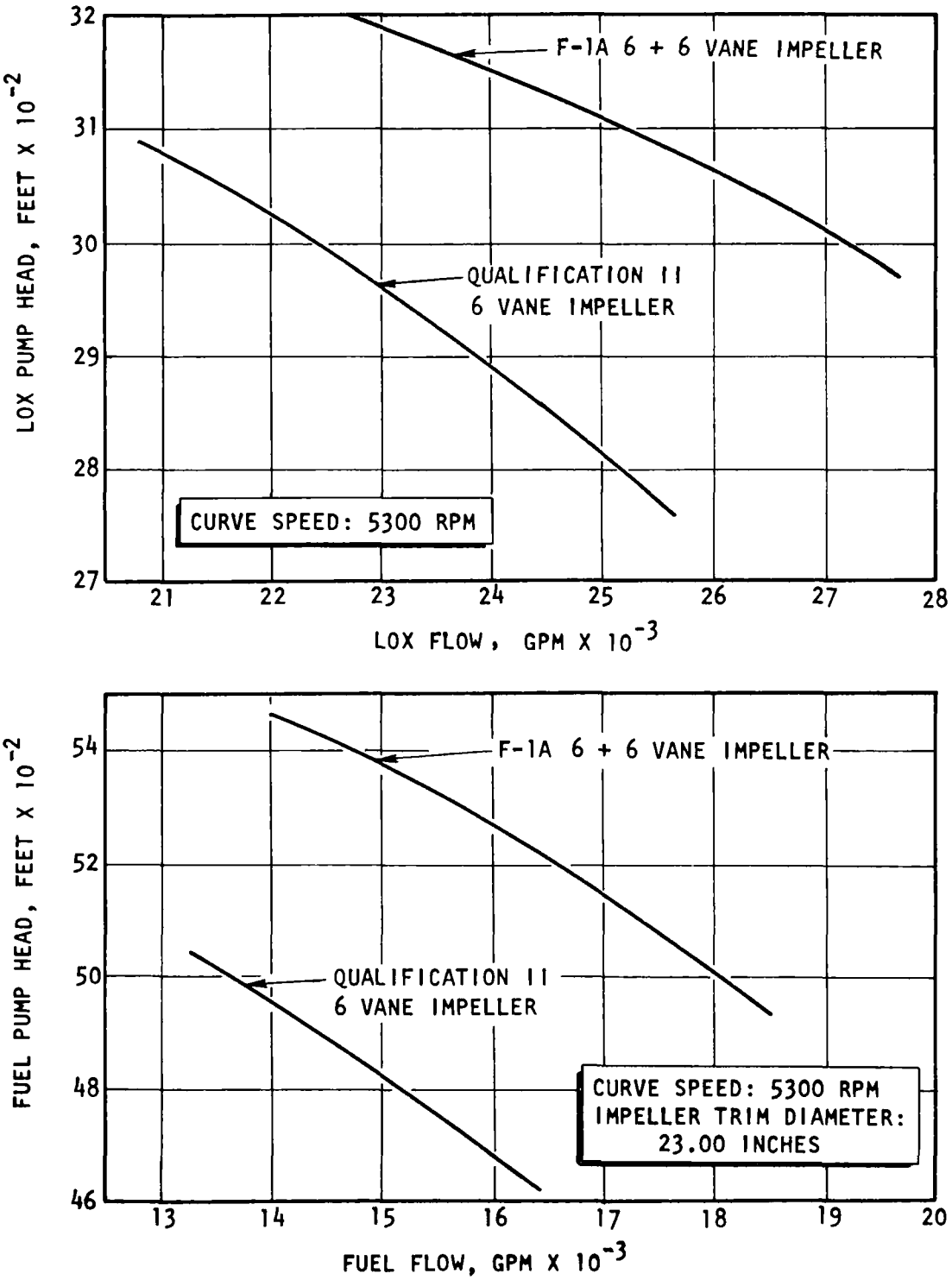


Figure 15. Comparison of Turbopump Head Flow Performance, Qualification II Engine vs F-1A Engine

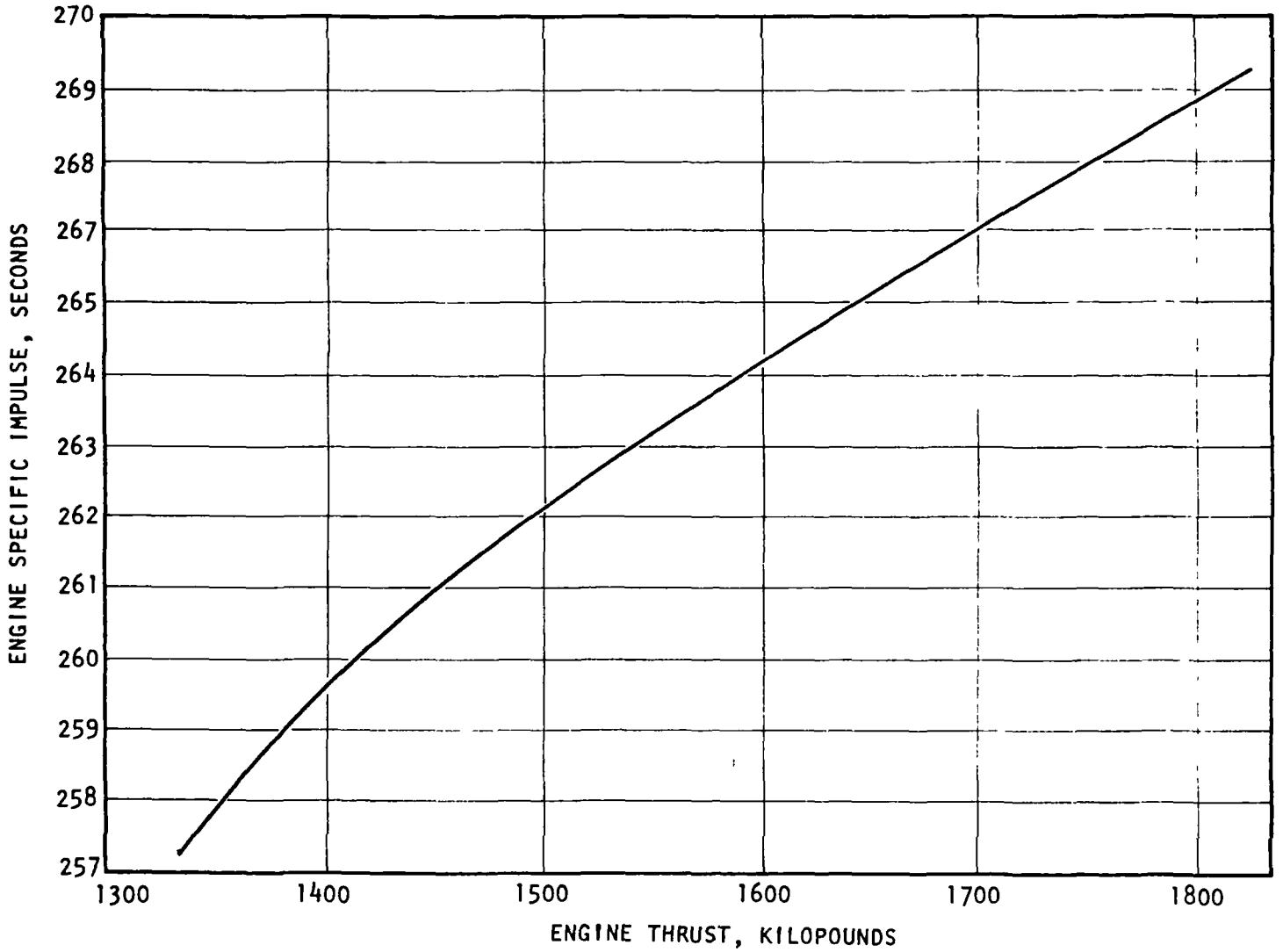


Figure 16. F-1A Engine Gas Generator Oxidizer Throttling Specific Impulse vs Thrust Level

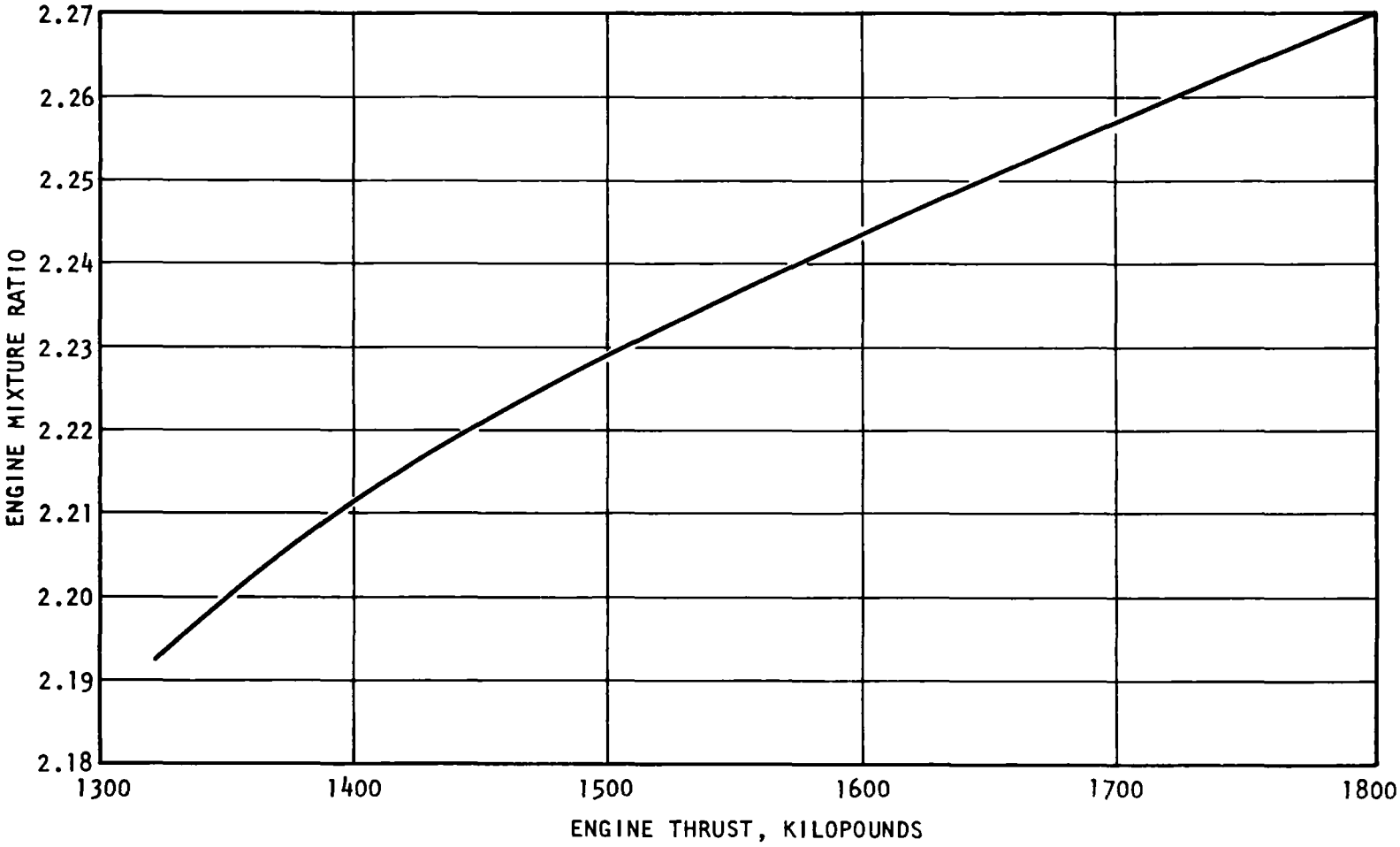


Figure 17. F-1A Engine Gas Generator Oxidizer Throttling Mixture Ratio vs Thrust Level

## GENERAL SYSTEM IMPROVEMENTS AND SIMPLIFICATIONS

The following improvements and/or simplifications have been incorporated into the F-1A engine to provide operational simplicity and reduced usage cost.

1. Turbopump improvements and simplifications consisting of a hydraulic warmant system for the thrust bearings, an internal axial thrust control system, and an internal bearing lubrication system.
2. Elimination of the complete fuel and oxidizer component overboard drain systems.
3. Incorporation of fluorosilicone elastomer seals in the fuel and hydraulic system joints.

### HYDRAULIC WARMANT SYSTEM FOR THRUST BEARINGS

This system utilized hydraulic fluid from the hydraulic control system to maintain a satisfactory thrust bearing temperature environment with oxidizer propellant in the engine. Incorporation of this system allowed elimination of the electrical heaters and associated thermostats and harnesses utilized by the Qualification II engine turbopump to maintain satisfactory thrust bearing temperature. Elimination of the electrical heater system completely eliminated the requirement for 208-vac power to the engine.

### TURBOPUMP INTERNAL AXIAL THRUST CONTROL SYSTEM

This system is completely contained within the fuel pump and requires no adjustments or calibrations. Incorporation of this system allowed elimination of two external flexible lines, the control orifice, and line support brackets included on the Qualification II engine turbopump for shaft axial thrust control.

## TURBOPUMP INTERNAL BEARING LUBRICATION SYSTEM

This system is completely contained within the turbopump and requires no calibration or moving parts. Incorporation of this system allowed elimination of the bearing lubrication jets, bearing coolant supply valve, overboard drain lines, and interconnecting plumbing used on the Qualification II engine turbopump for bearing lubrication.

## ELIMINATION OF FUEL AND OXIDIZER DRAIN SYSTEMS

The overboard drain lines provided from the vent ports between critical redundant dynamic seals in the fuel, hydraulic, and oxidizer system components on the Qualification II engine are eliminated on the F-1A engine. The vent ports between these redundant seals are equipped with low-pressure cracking check valves. Elimination of the drain lines is based on the high reliability experienced with these redundant dynamic seals on the Qualification II engine. By eliminating these drain lines, the individual vent ports are more accessible, and therefore easier to check for leakage during engine checkout. Elimination of the turbopump lubrication system overboard drain line, by incorporation of the internal lubrication system, and the fuel component dynamic seal drain lines completely eliminates the fuel overboard drain system.

## FLUOROSILICONE ELASTOMER SEALS

All static molded-in-place type seals in the fuel propellant and hydraulic system joints are provided with fluorosilicone elastomer on the F-1A engine to replace Viton A or Buna N elastomers used in similar joints in the Qualification II engine. Fluorosilicone elastomer does not require age control and is compatible with engine solvents. In addition, this material has exhibited satisfactory performance at extended temperature limits. Incorporation of fluorosilicone elastomer seals provides the F-1A engine with the following simplifications or improvements.

1. Eliminates all soft goods age control requirements.

2. Eliminates special servicing procedures such as the gas generator fuel servicing purge.

3. Allows relaxation of the engine environmental temperature limits.

4. Allows use of a single seal material in fuel and hydraulic systems joints. The Qualification II engines utilize Viton A and Buna N elastomer to achieve engine solvent and temperature compatibility.

## PRELIMINARY TEST PROGRAM RESULTS

An objective of the F-1A Task Assignment Program was to conduct component and engine tests to evaluate the feasibility of the new features incorporated into the F-1A engine system. The following is a discussion of the results of these preliminary test programs.

### IMPROVED START SEQUENCE EVALUATION

The F-1A engine start sequence is an all-pressure-ladder sequence, with each event occurring in series and initiated by a pressure signal provided by completion of a preceding event. This improved start sequence is described in the F-1A Engine System Design Requirements Specification (Appendix A). Another difference from the Qualification II engine start sequence is that thrust chamber propellant ignition is accomplished prior to gas generator propellant ignition. This allows use of the thrust chamber ignition flame as the ignition source for the turbine exhaust gas as it enters the thrust chamber, thus eliminating the requirement for electrically initiated pyrotechnic igniters provided on the Qualification II engine for this purpose. This change requires use of ground-supplied igniter fuel to rupture the hypergol cartridge and establish thrust chamber and gas generator propellant ignition.

An engine test program to evaluate the preceding features of the F-1A engine start sequence has been conducted on R&D engine 104-4. The hydraulic system plumbing on this engine was modified by the installation of a solenoid valve in each control line to a control element. Electrical timers were used to control the application of electrical power to each solenoid to achieve the desired sequencing. The ground hydraulic supply system was modified to provide igniter fuel to rupture the hypergol cartridge and sustain main thrust chamber ignition. The gas generator on engine 104-4 employed pyrotechnic igniters for ignition.

A total of 27 engine ignition and mainstage tests was conducted to evaluate the F-1A start sequence. Results of these tests showed that the series start sequence would be satisfactory, and that turbine exhaust gas ignition can be satisfactorily obtained with thrust chamber ignition flame. It was found that a ground-supplied main thrust chamber igniter fuel flowrate of 15 lb/sec was required to achieve repeatable ignition of the turbine exhaust gas. It would be expected that this igniter fuel flowrate could be substantially reduced with the incorporation of gas generator hypergol ignition. Hypergolic ignition requires an oxidizer lead which would prime the exhaust system with gaseous oxygen prior to gas generator ignition. This oxygen-rich environment would allow the gas generator produced gas to remain ignited as it flows through the exhaust system to the thrust chamber.

## GAS GENERATOR HYPERGOL IGNITION EVALUATION

The design requirements for the gas generator hypergol ignition system are described in the F-1A Engine System Design Requirements Specification (Appendix A). A component test program to evaluate gas generator hypergol ignition was conducted at test facility Bravo-1A. A modified Qualification II engine type gas generator valve with additional facility valves and plumbing was provided to achieve the desired sequencing. A Qualification II engine type Mod 4 injector was modified by the incorporation of an igniter fuel passage to a center spray disk on the injector face.

A series of 19 tests was conducted. Results showed that satisfactory ignition characteristics would be achieved with an igniter fuel flowrate in the range of 0.1 to 0.15 lb/sec over the allowable ranges of engine prestart turbopump oxidizer and fuel pump inlet pressures. It was also shown that when main fuel is introduced into the gas generator combustor body, smooth ignition and pressure buildup would occur.

Servicing procedures to remove residual fuel from the injector fuel passages and igniter fuel supply line downstream of the hypergol cartridge were also developed during this test program. These procedures would

eliminate residual fuel from the passages downstream of the hypergol cartridge by use of a gas purge and would remove residual fuel from the gas generator injector fuel passages by use of a solvent flush. The potential for accumulation of residual fuel in the igniter fuel supply line and in the combustor body would be significantly reduced in the F-1A engine by the design which provides for gravity drainage at both locations.

## THRUST CONTROL SYSTEM EVALUATION

An engine test program was conducted on R&D engine 109-4 to determine gas generator and thrust chamber combustion stability characteristics when the thrust level is throttled, and to define engine steady-state performance gains with gas generator oxidizer-side throttling. The throttle valve and servomotor used for this program were derived from a modified J-2 engine propellant utilization valve. The valve position controller, programmer, and thrust profile generator used were facility equipment and not of a flight configuration. A total of seven engine mainstage tests was conducted, during which engine thrust was varied over the range of 1,250,000 to 1,840,000 pounds.

The first three tests demonstrated open-loop throttling, with throttle valve position signals supplied by preset facility potentiometers. The last four tests demonstrated closed-loop throttling, with throttle valve position controlled by the output electrical signal from a flight pressure transducer monitoring thrust chamber fuel injector manifold pressure. During these tests no pressure oscillations were experienced in the gas generator and thrust chamber at thrust levels greater than 1,300,000 pounds. Intermittent gas generator chamber pressure oscillations were experienced in the region of 1,250,000 pounds thrust. Figure 18 shows thrust vs time resulting from open-loop gas generator oxidizer-side throttling. Figures 19 and 20 show the corresponding main chamber pressure and gas generator chamber pressure during this test.

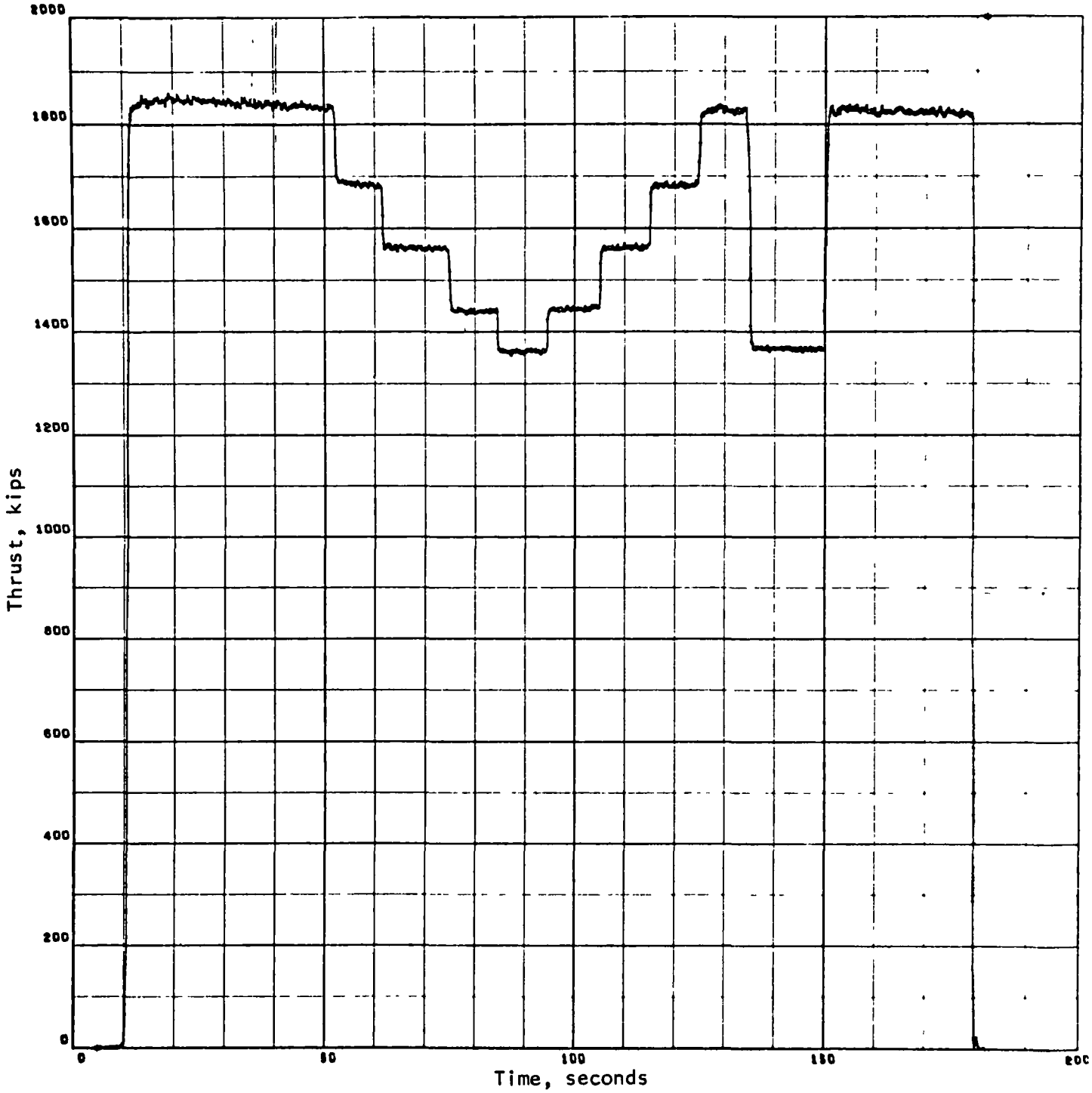


Figure 18. Engine 109-4 Gas Generator LOX Side Open-Loop Throttling

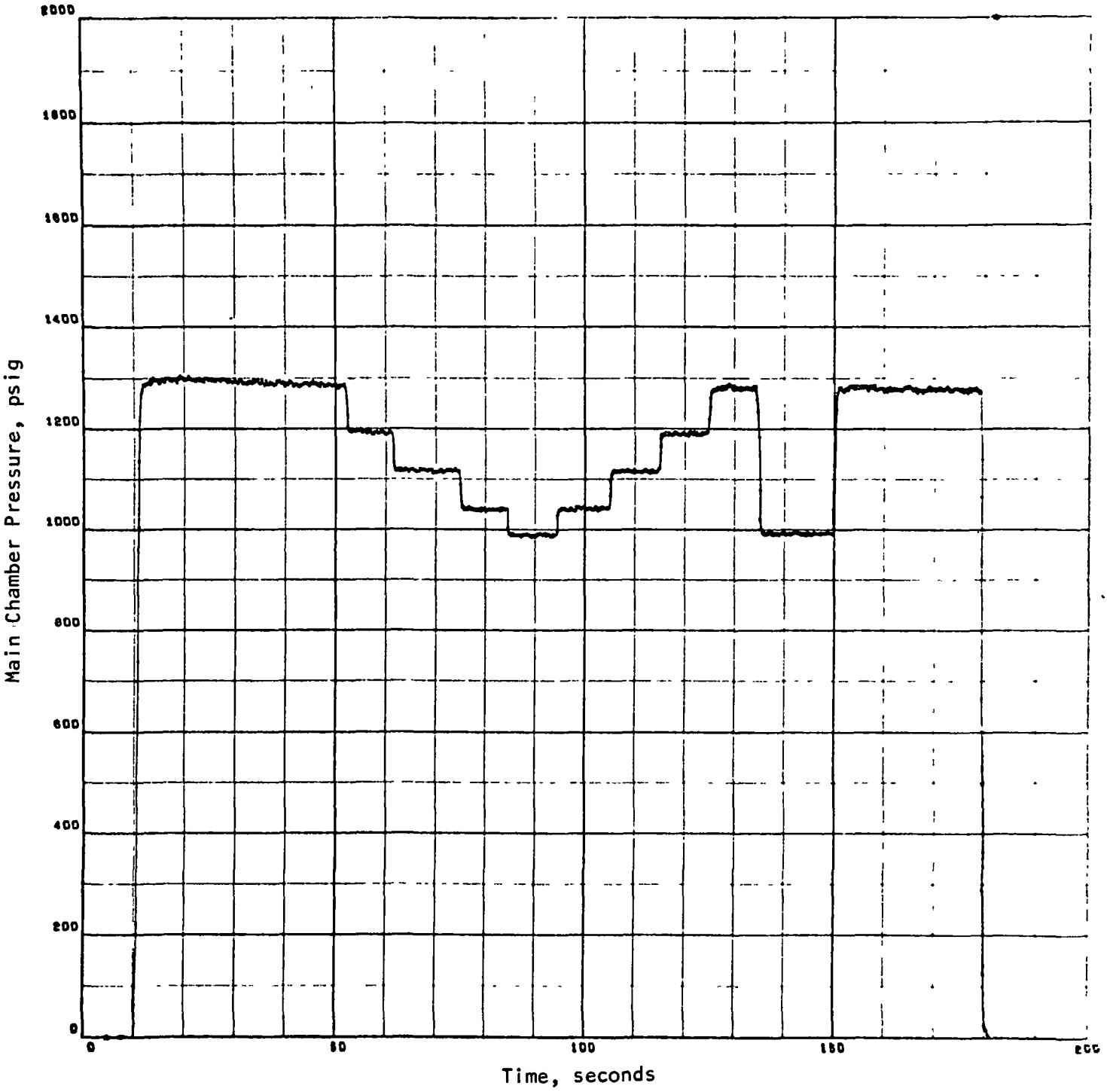


Figure 19. Engine 109-4 Gas Generator LOX Side Open-Loop Throttling

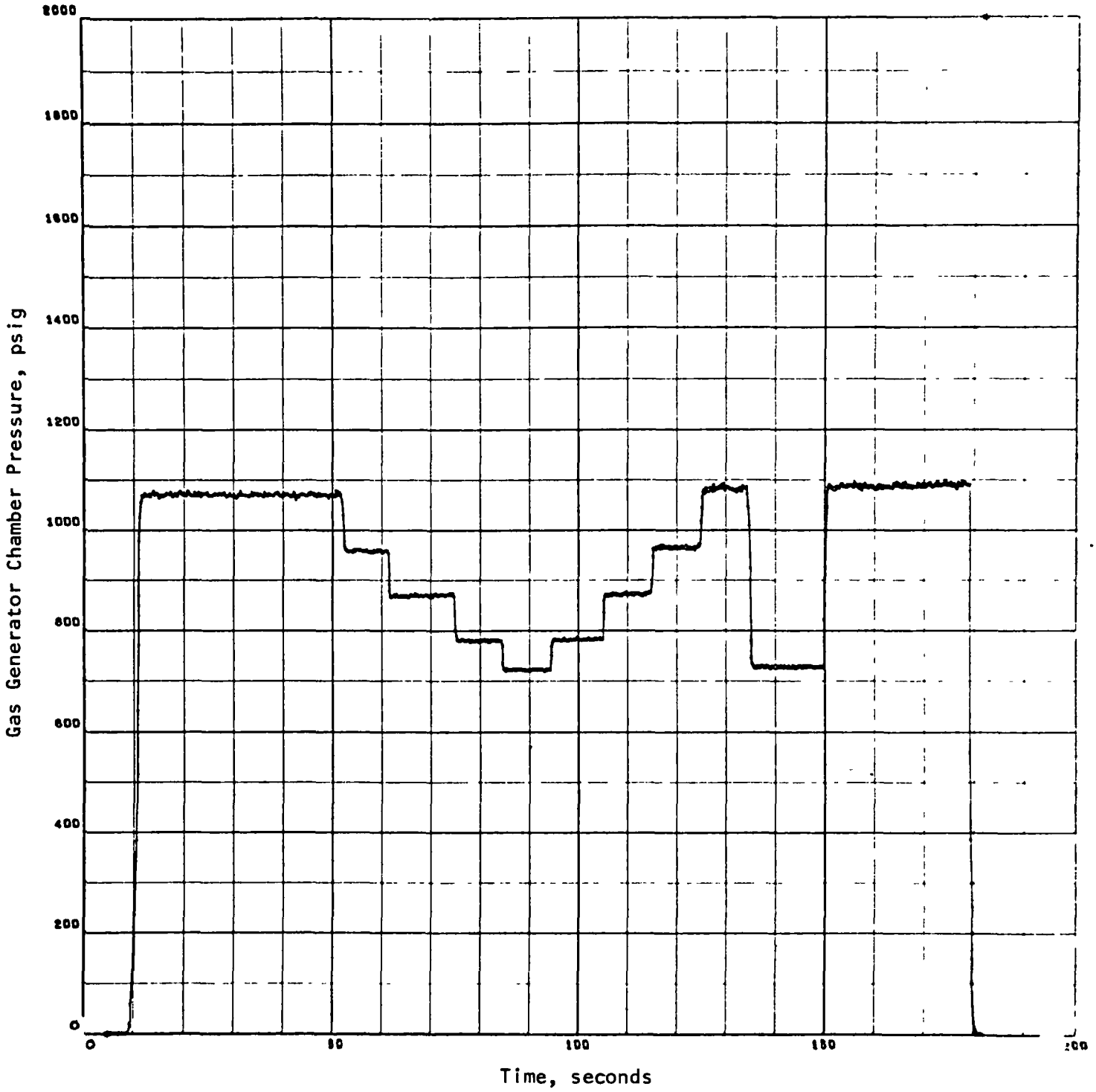


Figure 20. Engine 109-4 Gas Generator LOX Side Open-Loop Throttling

## TURBOPUMP BEARING WARMANT EVALUATION

The turbopump bearing warmant system circulates hydraulic control system fluid through passages in the bearing heater housing to maintain the required temperature environment in the thrust bearing area with oxidizer in the engine. Laboratory and component tests have been conducted to evaluate this system. Results of these tests showed that the minimum outer bearing race temperature of 0 F could be maintained with a hydraulic fluid flowrate greater than 2 gpm, providing the fluid temperature is maintained above 60 F. For the case when the fluid temperature is reduced to 30 F, a flowrate of 8 gpm would be required. These tests showed that elimination of the turbopump electrical heater is feasible.

## OXIDIZER DOME OPERATIONAL PURGE ELIMINATION EVALUATION

The oxidizer dome operational purge is used on the Qualification II engine to prevent contamination of the thrust chamber and gas generator oxidizer domes and injector oxidizer passages, and to control temperature in the gas generator during engine shutdown for static tests. This system is not required for engine shutdown during flight. An engine test program has been conducted to determine whether the purge could be eliminated by employing a posttest solvent flushing procedure to clean the dome and injector surfaces of any contaminants. Results from a limited number of tests indicated that elimination of the purge system is feasible.

## F-1A ENGINE STATUS

Detail and assembly drawings for all F-1A components have been completed. Table 9 presents a listing of the major components and their drawing numbers. Installation drawings and some top assembly drawings have been started but not completed. All drawing vellums have been stored in the drawing vault for easy retrieval. A complete file of F-1A engine drawings is available at the F-1 project office.

Fabrication of F-1A hardware is approximately 40 percent complete. Of the major hardware, the thrust chamber is 50 percent complete, the turbopump is approximately 95 percent complete including component hot-fire testing, and fabrication of control system hardware is approximately 20 percent complete.

An F-1A task assignment closeout plan of action has been completed to provide the capability for timely reactivation of the program when required. The plan provided for completion of an engine mockup, controlled storage of hardware and raw material, and preparation of a master file of F-1A drawings, reports, specification, photos, schedules, analyses, and other pertinent documentation.

It is estimated that engine 115-4, the F-1A task assignment engine, could be assembled and made ready for testing 10 months after reactivation "Go Ahead."

TABLE 9

F-1A ENGINE COMPONENTS MAJOR PARTS LIST

| Nomenclature | Part Number |
|---|---|
| Gas Generator Assembly | 99-309200 |
| Gas Generator Valve | 99-309400 |
| Gas Generator Injector | 99-309179 |
| Gas Generator Combustor Body | 99-309177 |
| Oxidizer Throttle Valve | 99-251001 |
| Thrust Chamber Assembly | 211031X |
| Thrust Chamber Body | 211032X |
| Hydraulic Manifold Subassembly | 211036X |
| Main Oxidizer Valve | 99-411635 |
| Main Fuel Valve | 99-411700 |
| Turbopump Assembly | 462075X |
| Engine Control Unit | 99-558675 |
| Engine Arming Unit | 99-558700 |
| Ignition Control Unit | 99-557607 |
| Sequence Instrumentation Unit | 99-557607 |
| Hydraulic Gimbal Supply Manifold, No. 1 | 602269X |
| Hydraulic Gimbal Supply Manifold, No. 2 | 602270X |
| Hypergol Cartridge Assembly | 99-652069 |

| PREPARED BY | CODE IDENT. NO.: 02602 | NUMBER RYF-1AL04-01005 |
|---|---|---|
| S. C. Nethery, Jr. | ROCKETDYNE<br>A DIVISION OF NORTH AMERICAN ROCKWELL CORPORATION | TYPE Design |
| APPROVALS | | DATE 15 December 1969 |
| | SPECIFICATION | SUPERSEDES SPEC. DATED: 15 November 1968 |
| | | REV. LTR. B / PAGE 1 of 87 |

TITLE

F-1A ENGINE SYSTEM

APPENDIX A

F-1 ENGINE SYSTEM DESIGN REQUIREMENTS SPECIFICATION

CONTENTS:

SECTION 1 - SCOPE

SECTION 2 - APPLICABLE DOCUMENTS

SECTION 3 - REQUIREMENTS

SECTION 4 - QUALITY ASSURANCE PROVISIONS

SECTION 5 - PREPARATION FOR DELIVERY

SECTION 6 - NOTES

SECTION 10- APPENDIX

## GENERAL

1. All symbols, abbreviations, and terms coded with a superscript (1) are defined in Section 6 of this specification.

2. This specification is written for the F-1A Uprated, Simpified Engine and deviations to these requirements for the Task Assignment Engine 115-4 will be specified in Section 10.

3. To clarify and ease the description of the engine system and component locations on the engine system, the engine has been divided into the Number One Side[1] and the Number Two Side[1]. All duplicate components will be identified by the installed location on the engine for example, the Number 1 main oxidizer valve is the main oxidizer valve installed on the Number 1 side of the engine.

4. Functional descriptions of the operation of the Operational Control System and the Sequence Instrumentation Unit are provided in Paragraph 6.1, Supplemental Information.

## REVISION STATUS SUMMARY

This Specification is intended to be in a continual state of revision. It is the responsibility of the using individual to ascertain latest revision status. This Summary is intended to aid the user in determining the affected sections and/or paragraphs contained in this revision. All changes incorporated subsequent to the last revision are indicated by the symbol in the left margin at numbered paragraphs. The change symbol | applies to the entire numbered paragraph indicated.

| Revision Number | Date | Changes |
|---|---|---|
| 01001 | 7/5/68 | Initial Issue |
| 01002 | 8/16/68 | Complete Reissue |
| 01003 | 9/27/68 | Complete Reissue |
| 01003A | 11/15/68 | Complete Reissue |
| 01003B | 12/15/69 | Complete Reissue |

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1. SCOPE - This specification establishes the requirements for performance, design and test of one design of equipment identified as the Rocketdyne F-1A Liquid Propellant Rocket Engine. This engine is used to provide primary thrust for launch vehicles.

The F-1A engine is a variable thrust, calibrated engine with a nominal sea level thrust rating of 1,800 kips. The engine thrust rating is adjustable between 1,800 kips and 1,350 kips. Throttling is provided for 300 kips below the calibration rating not to exceed the minimum thrust rating level. This engine requires electrical power and hydraulic power from ground sources for engine starting plus electrical power during flight from the vehicle. This engine utilizes liquid oxygen as the oxidizer and RP-1 as the fuel to produce thrust. The engine can be used in single or multi-engine installations and is capable of restart after servicing.

This specification has been prepared using as a guide those portions of NPC-500, Apollo Configuration Management Manual, that are applicable to the preparation of a design requirement specification (Part I) for a Contract End Item (Prime Equipment).

2. APPLICABLE DOCUMENTS - The following documents, of exact issue shown, form a part of this specification to the extent specified herein. In event of a conflict between documents referenced here and other detailed content of Sections 3 and 4, the detail requirements of Sections 3 and 4 shall govern.

SYSTEM PROGRAM DOCUMENTS

SPECIFICATIONS

Federal
(TBD)

Military

| | |
|---|---|
| MIL-E-5272C<br>20 January 1960 | Environmental Testing, Aeronautical and Associated Equipment, General Specification |
| MIL-S-7742A<br>2 December 1959 | Screw Thread, Standard, General Specification for |
| MIL-I-6181D<br>22 June 1965 | Interference Control Requirements Aircraft Equipment |
| MIL-S-8879<br>21 September 1960 | Screw Threads, Controlled Radius with Increased Minor Diameter, General Specification for |
| MIL-P-25508C<br>7 November 1960 | Propellant, Oxygen |
| MIL-P-25576C<br>10 February 1967 | Propellant, Kerosene |
| MIL-P-27401B<br>19 September 1962 | Propellant Pressurizing Agent, Nitrogen |
| MIL-F-25558B<br>14 March 1963 | Fuel, Ramjet Engine, Grade RJ-1 |
| MIL-F-5606B<br>26 June 1963 | Hydraulic Fluid, Petroleum Base, Aircraft, Missile, and Ordnance |

North American Rockwell Corporation

| | |
|---|---|
| RA0104-007 | Serial Numbers, Determination and Marking of |
| RA0104-008 | Marking, Identification Parts, Assys/End Items |

| | |
|---|---|
| RA0107-027 | Process/Quality Requirements for Fusion Welds |
| RA0115-006 | Inspection, Radiographic |
| RA0607-050 | In Place Fabrication Requirements for Corrosion and Heat Resistant Steel Tubular Systems on F-1 Engines |

STANDARDS

Federal

| | |
|---|---|
| USDC-9198<br>1 February 1966 | Cryogenic Propellant Fluid Properties Final Report for Data Evaluation Program on Government Order H-76797 |
| NASA, USAF, US Weather Bureau | US Standard Atmosphere, 1962 |

Military

| | |
|---|---|
| MIL-STD-130B<br>24 April 1962 | Identification Marking of U.S. Military Property |

North American Rockwell Corporation

| | |
|---|---|
| RP260-1001 | Instrumentation Boss, Straight Thread, Gasket Seal, Standard Dimensions for |

DRAWINGS

| | |
|---|---|
| AND10375 | Colors, Fluid Line Identification |

BULLETINS

| | |
|---|---|
| ANA 343n<br>14 December 1960 | Specifications and Standards Applicable to Aircraft Engines and Propellers, Use of |

OTHER PUBLICATIONS

Manuals

| | |
|---|---|
| R3950(Rev)<br>10 August 1965 | Contractor Responsibility for use with NASA Contracts |
| R-3896-3 | F-1 Engine Maintenance and Repair Manual |
| R-3896-5 | F-1 Engine Ground Support Equipment |

| | |
|---|---|
| R-3896-9 | F-1 Engine Transportation Manual |
| R-6749 | F-1 Engine Interface Document |
| NPC-500 | Apollo Configuration Management Manual (NASA) |

Regulations
(TBD)

Handbooks
(TBD)

3. REQUIREMENTS

3.1 PERFORMANCE

3.1.1 FUNCTIONAL CHARACTERISTICS

3.1.1.1 PRIMARY PERFORMANCE CHARACTERISTICS

3.1.1.1.1 EFFECTIVE DURATION - The rated effective duration[1] of the engine shall be (TBD) seconds.

3.1.1.1.2 STEADY STATE PERFORMANCE RATINGS - Engine steady state performance ratings shall be in accordance with Table A-1 and shall be based on the conditions of paragraph 3.1.1.1.2.1 Standard Conditions.

TABLE A-1

ENGINE RATINGS AT STANDARD CONDITIONS

| | | |
|---|---|---|
| Thrust | Kips | 1800 |
| Mixture Ratio | | 2.27 |
| Specific Impulse | Seconds (Minimum) | (TBD) |

3.1.1.1.2.1 STANDARD CONDITIONS - The following conditions are applicable to the engine performance ratings of thrust, mixture ratio, and specific impulse.

a. PERFORMANCE DATA INTERVAL - Performance ratings shall be based on a performance data interval equal to or greater than 3.0 seconds and equal to or less than 3.2 seconds, occurring between 35.0 and 40.0 seconds effective duration[1].

b. ATMOSPHERIC PRESSURE - Performance ratings shall be based on engine operation at standard sea-level atmospheric pressure[1] per US Standard Atmosphere, 1962.

c. PUMP INLET PROPELLANT CONDITIONS - Performance ratings shall be based on use of RP-1 fuel in accordance with MIL-P-25576C at a temperature of 60F and a density of 50.45 pound/ft$^3$, supplied to the pump inlet at a pressure of 45 psia (total) and the use of liquid oxygen in accordance with MIL-P-25508C at a density of 71.38 pound/ft$^3$ per the National Bureau of Standards Report USDC-

9198, supplied at the pump inlet at a pressure of 65 psia (total).

3.1.1.1.2.2 THRUST - Engine thrust shall be the average reactive force created by the consumption of oxidizer and fuel by the engine, as corrected to the conditions of paragraph 3.1.1.1.2.1 Standard Conditions.

a. THRUST RATING - The rated thrust shall be 1800 kips.

b. THRUST RATING CAPABILITY - The engine system shall be capable of being rated at any thrust between 1800 and 1350 kips.

c. THRUST ADJUSTMENT CAPABILITY - The engine system shall be capable of adjusting thrust through a 300 kips bandwidth during operation to within ±30 kips of any predetermined thrust in this range. This thrust adjustment bandwidth shall be contained within the 1800 kips to 1350 kips rating capability limits.

d. THRUST ADJUSTMENT RATE - The thrust adjustment shall be performed such that an increase in thrust for any 0.01 second time interval is between (TBD) and (TBD) kips and such that a decrease in thrust for any 0.01 second interval is between (TBD) and (TBD) kips.

3.1.1.1.2.3 MIXTURE RATIO - Engine mixture ratio shall be the ratio of average oxidizer consumption to average fuel consumption in pounds per second, corrected to rated thrust and the conditions of paragraph 3.1.1.1.2.1 Standard Conditions.

a. MIXTURE RATIO RATING - The rated mixture ratio shall be 2.27.

b. MIXTURE RATIO RATING CAPABILITY - The engine system shall be capable of being rated at any mixture ratio between 2.15 and 2.35.

c. THRUST ADJUSTMENT MIXTURE RATIO EFFECT - The engine system shall be capable of maintaining engine mixture ratio, corrected to the conditions of paragraph 3.1.1.1.2.1 Standard Conditions, as shown in Figure (TBD) while adjusting thrust in accordance with paragraph 3.1.1.1.2.2.c Thrust Adjustment Capability.

d. MIXTURE RATIO CAPABILITY - The engine shall be capable of safe and stable operation at any mixture ratio between 2.00 and 2.50.

3.1.1.1.2.4 SPECIFIC IMPULSE - Engine specific impulse shall be the thrust in pounds divided by the combined average oxidizer and fuel consumption in pounds per second, as corrected to rated thrust in accordance with paragraph 3.1.1.1.2.2a Thrust Rating and rated mixture ratio in accordance with paragraph 3.1.1.1.2.3a Mixture Ratio Rating and the conditions of paragraph 3.1.1.1.2.1 Standard Conditions. Engine specific impulse shall be equal to or greater than (TBD) seconds.

3.1.1.1.2.5 ENGINE ALIGNMENT - The engine shall be designed to meet the following requirements.

a. ACTUAL THRUST VECTOR - The actual thrust vector[1] shall be within 30 minutes of the engine centerline[1] and pass within 0.600 inch of the gimbal center[1].

b. THRUST CHAMBER CENTERLINE - The thrust chamber centerline[1] shall be within 30 minutes of the engine centerline[1] and pass within 0.250 inch of the gimbal center.

3.1.1.1.3 STARTING - The engine shall be designed for one ground start only without reservicing. The starting sequence shall be automatic upon receipt of an externally supplied start signal. Required ground control and safety circuits shall be in accordance with paragraph 3.2.1 Interface Requirements. The requirements of paragraphs 3.1.1.1.3.1 Starting Time and 3.1.1.1.3.2 Thrust Increase shall apply for engine operation in accordance with paragraphs 3.2.1 Interface Requirements, and 3.1.2.4 Environment. The typical engine starting sequence is presented in Figure A-1 and estimated[1] engine thrust increase characteristics are presented in Figure (TBD).

3.1.1.1.3.1 STARTING ATTITUDE - The engine shall be designed to start in a thrust chamber nozzle down attitude with the thrust chamber centerline[1] not exceeding a cant of 3 degrees from the true vertical (3 degree half angle cone), provided that thrust chamber prefill fluid level is at a level in accordance with paragraph 3.1.2.7.2.17 Lowered Prefill.

3.1.1.1.3.2 STARTING TIME - The time from engine control valve open signal to the attainment of 90 percent of target thrust[1] shall not exceed 3.000 seconds, as corrected to pre-start pump inlet standard conditions[1].

3.1.1.1.3.3 THRUST INCREASE - The increase in thrust for any 0.010 second time interval of the thrust buildup transient between

6 percent and 65 percent of target thrust shall not exceed 200 kips. The increase in thrust for any 0.010 second time interval of the thrust transient above 65 percent of target thrust shall not exceed 100 kips. The elapsed time between 40 percent and 90 percent of target thrust[1] shall not be less than 0.400 seconds.

3.1.1.1.4 SHUTDOWN - The engine shall be designed for positive shutdown under all operating conditions after receipt of a signal from a ground or vehicle/stage source. The typical engine shutdown sequence is presented in Figure A-2 and estimated[1] engine thrust decrease characteristics are presented in Figure (TBD).

3.1.1.1.4.1 SHUTDOWN TIME - The time from engine stop signal to the attainment of 10 percent of the thrust at the receipt of the engine stop signal shall be no more than 0.750 seconds nor less than 0.350 seconds. The time from engine stop signal to (TBD) thrust shall not exceed 2.000 seconds.

3.1.1.1.4.2 THRUST DECREASE - The decrease in thrust for any 0.075 second interval during the thrust decay transient shall not exceed 415 kips.

3.1.1.1.4.3 CUTOFF IMPULSE - Cutoff impulse shall be the time integral of the total longitudinal reactive force output of the engine following receipt of an engine stop signal. Cutoff impulse shall not be more than (TBD) kip-seconds nor less than (TBD) kip-seconds.

3.1.1.1.5 WEIGHT PROPERTIES - The engine and accessories shall be designed with the following weights as goals:

a. Dry Weight - The dry weight[1] of the engine and accessories shall not exceed TBD pounds.

b. Wet Weight - The wet weight[1] of the engine and accessories shall not exceed TBD pounds.

c. Burnout Weight - The burnout weight[1] of the engine and accessories shall not exceed TBD pounds.

3.1.1.1.6 GIMBAL PROPERTIES - The engine shall be designed with the following gimbaling capability, mass characteristics, and restraints for the engine and accessories as goals:

a. The engine axes[1] shall be in accordance with Figure A-3.

b. The engine shall be capable of being gimbaled within a square pattern of plus and minus 6 degrees maximum in the actuation planes from the delivered aligned engine position[1] within

the limits of paragraph 3.1.2.4.6c Gimbal Loads, paragraph 3.1.1.1.2.4 Engine Alignment, and paragraph 3.1.2.4.6d Flight Acceleration Loads. The maximum angular acceleration shall be 30 radians/second$^2$.

c. The wet gimbaled mass[1] characteristics are as follows.

1. Moment of Inertia about Engine axis Iy = TBD slug ft squared.

2. Moment of Inertia about Engine axis Ix = TBD slug ft squared.

3. Moment of Inertia about Engine axis Iz = TBD slug ft squared.

4. Center of Gravity

| | | |
|---|---|---|
| | y = | TBD inches |
| | x = | TBD inches |
| | z = | TBD inches |

5. Weight TBD pounds

d. The gimbaling moment restraints shall be those specified in paragraph 3.2.1 Interface Requirements.

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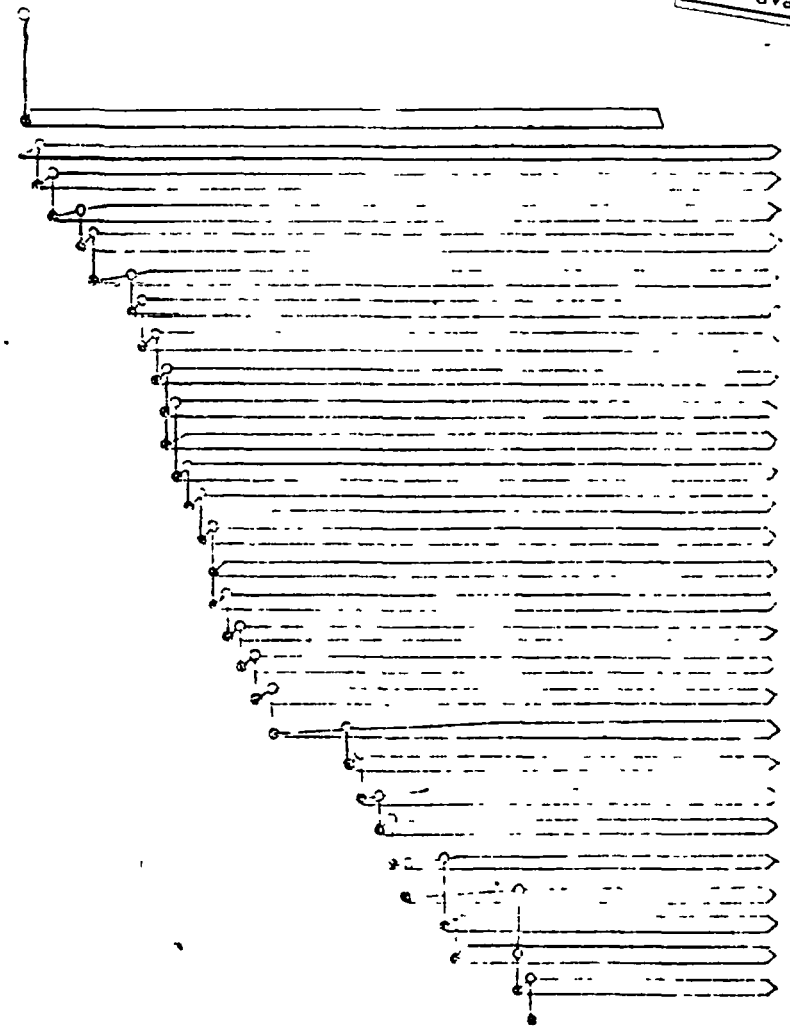
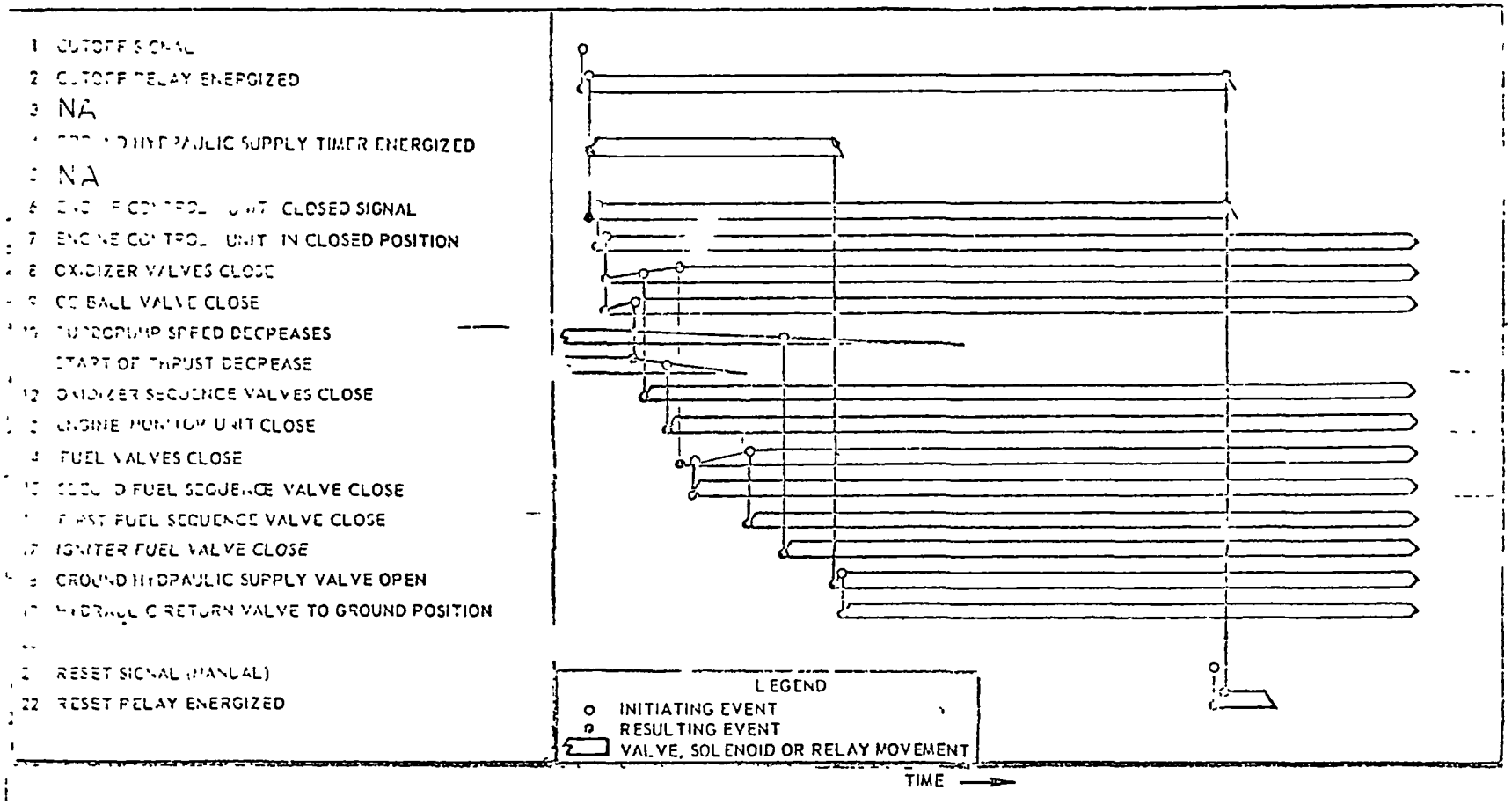
1. Start Signal (Manual)
2. NA
3. NA
4. [illegible] Under Test Enabled
5. [illegible] Control Unit Open Signal
6. Engine Control Unit In Open Position
7. No. 2 Main Oxidizer Valve Open
8. No. 2 Oxidizer Sequence Valve Open
9. No. 1 Main Oxidizer Valve Open
10. No. 1 Oxidizer Sequence Valve Open
11. Gas Generator LOX Valve Open
12. Gas Generator Sequence Valve Open
13. Igniter Fuel Control Valve Open
14. Hydraulic Return Control Valve (Engine)
15. Igniter Fuel Shutoff Valve Open
16. GG Hypergol Cartridge Rupture
17. GG Ignition System Prime
18. GG Combustor Ignition
19. Thrust Chamber Hypergol Cartridge Rupture
20. Thrust Chamber Ignition
21. Ignition Monitor Valve Actuates
22. GG Fuel Valve Open
23. Turbopump Speed Increases
24. MFV Control Valve Actuates
25. No. 2 Main Fuel Valve Open
26. No. 2 Fuel Sequence Valve Open
27. No. 1 Main Fuel Valve Open
28. Main Thrust Increase
29. No. 1 Fuel Sequence Valve Open
30. Engine Monitor Valve Actuates
31. Pressure Switches Actuate
32. Start Sequence Complete/Launch Commit



LEGEND

- Initiating Event
- Resulting Event
- Valve, Solenoid or Relay Movement

FIGURE A-1
ENGINE START SEQUENCE
(HYPERGOL GG IGNITION)




ENGINE STOP

Figure A-2



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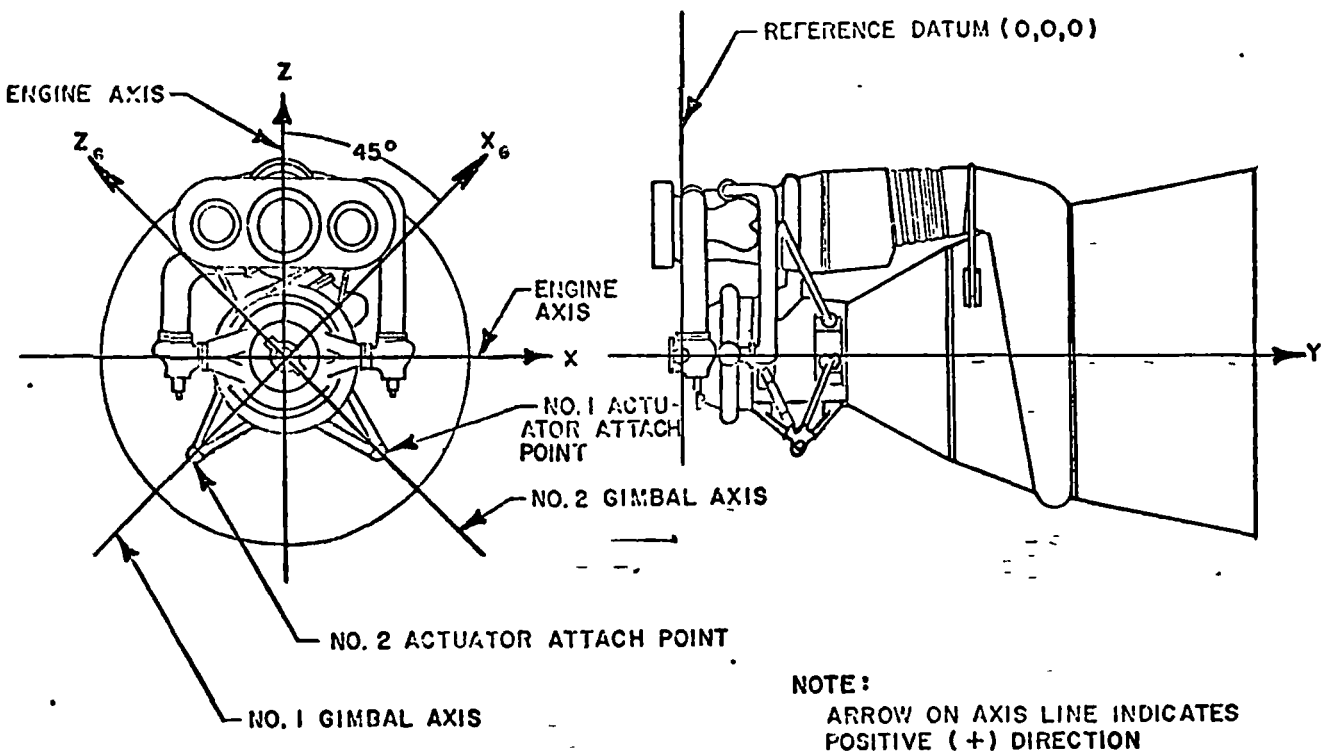
Figure A-3

ENGINE AXES




NOTE:
ARROW ON AXIS LINE INDICATES POSITIVE (+) DIRECTION

3.1.1.2 SECONDARY PERFORMANCE CHARACTERISTICS - The engine system is divided into nine systems for the purpose of describing the secondary performance characteristics and requirements. These systems are the Thrust System, the Fuel Feed System, the Oxidizer Feed System, the Turbine Drive and Exhaust System, the Operational Control System, the Ignition System, the Thrust Control System, the Instrumentation System and the Stage/Vehicle Service System.

Internal Engine system estimated[1] operating pressures, flowrates and temperatures have been generated for two potentially deliverable engine configurations. These two system configurations are: Gas Generator Oxidizer Throttled Engine[1], Calibrated Orificed Engine[1]. In addition estimated[1] operating pressures, flowrates and temperatures were generated for the Uncalibrated Orificed Engine[1] tested at EFL. In the preparation of these estimates the thrust chamber properties used are those contained in (TBD). The gas generator/turbine hot gas properties are those contained in (TBD). Table B-1 tabulates these estimated internal environments as follows.

1. GAS GENERATOR OXIDIZER THROTTLED ENGINE[1]- Sheet 1 summarizes the internal operating pressure environment of all engine sub-systems. Sheets 2 and 3 summarize the remaining parameters i.e. temperature, turbopump power, and flowrates.

2. CALIBRATED ORIFICED ENGINE[1] - Sheet 4 summarizes the internal operating pressure environment for all engine sub-systems. Sheets 5 and 6 summarize the remaining parameters.

3. UNCALIBRATED ORIFICED ENGINE[1] - Sheet 7 summarizes the internal operating pressure environment for all engine sub-systems. Sheet 8 and 9 summarize the remaining parameters.

The definitions and descriptions of the terms used in Table B-1 are as follows.

1. NOMINAL - The parameter values resulting from operating an engine at rated thrust (1800K), mixture ratio (2.27) and turbine inlet manifold temperature (1500F) at the standard conditions for performance ratings and utilizing components with average secondary characteristics (e.g., fluid resistance, expansion ratio).

2. ALTERNATE RATINGS EFFECT - The maximum changes in a parameter value resulting from operating the engine at any alternate combination of thrust rating and mixture ratio rating within the rating capability limits.

3. THROTTLING EFFECT - The maximum changes in a parameter value resulting from adjusting engine thrust from any thrust and mixture ratio rating combination within the rating capability limits to any other thrust rating, subject to adjustment limitations imposed by alternate rating and thrust adjustment capabilities.

4. EXPECTED VALUES - The maximum value resulting from adding to the nominal the maximum increase of either the alternate ratings effect or the throttling effect and the minimum value resulting from subtracting from the nominal the maximum of the decreases associated with either the alternate ratings effect or the throttling effect.

5. RANDOM EFFECTS - The maximum increase in a parameter value which can add to an expected maximum and the maximum decrease in a parameter value which can subtract from an expected minimum as a result of variations in atmospheric pressure and pump inlet propellant conditions and variations in secondary characteristics, (e.g., fluid resistance, expansion ratio), subject to the control of the thrust control system.

6. MAXIMUM OSCILLATIONS - The maximum value of zero to peak pressure oscillations.

7. STEADY STATE OPERATING MINIMUM - The lowest steady state operating value which can result from any one of the following:

a. Operation of an uncalibrated, gas generator oxidizer throttled engine at any allowable combination of atmospheric pressure and pump inlet propellant conditions and with consideration of alternate rating combinations and thrust throttling, within thrust rating, mixture ratio rating, and thrust adjustment capabilities.

b. Operation of a calibrated orificed engine at any allowable combination of atmospheric pressure and pump inlet propellant conditions and with consideration of alternate rating combinations within thrust rating and mixture ratio rating capabilities.

c. Operation of an uncalibrated orificed engine under normal Edwards Field Lab acceptance test conditions, with consideration of variations in site atmospheric pressure and pump inlet propellant conditions and to alternate rating combinations within thrust rating and mixture ratio rating capabilities.

8. STEADY STATE OPERATING MAXIMUM - The highest steady state operating value, including oscillation peaks when applicable, which can result from any one of the operations described in Item 7, (a, b, and c).

9. MAXIMUM OPERATING INCLUDING SURGES - The result of adding to the maximum steady state operating level the maximum surges that occur during operation.

The sub-systems covered in paragraph 3.1.1.2 Secondary Performance Characteristics, provide a summary of the internal pressure environments from Table B-1. These summary tables contain the nominal/minimum/maximum pressure levels to be encountered by the engine system during any operation. The engine system shall be designed to meet these requirements in accordance with paragraph 3.3 Design and Construction.

# TABLE B-1
## INTERNAL OPERATING PRESSURE ENVIRONMENT
## GAS GENERATOR OXIDIZER THROTTLED ENGINE
## SHEET 1 OF 9

| SYSTEM | COMPONENT NAME | NOMINAL VALUE | ALTERNATE RATINGS EFFECT | | THROTTLING EFFECT | | EXPECTED VALUES | | RANDOM EFFECTS | | MAXIMUM OSCILLATIONS | STEADY STATE OPERATING | | MAXIMUM OPERATING INCLUDING SURGE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | MAXIMUM DECREASE | MAXIMUM INCREASE | MAXIMUM DECREASE | MAXIMUM INCREASE | MINIMUM | MAXIMUM | MAXIMUM DECREASE BELOW EXPECTED MINIMUM | MAXIMUM INCREASE ABOVE EXPECTED MAXIMUM | | MINIMUM | MAXIMUM | |
| FUEL FEED | PUMP INLET | 41 4 | 0 3 | 1 5 | 0 0 | 0 9 | 41 1 | 42 9 | 20 | 65 | 45 | 21 1 | 152 9 | 252 9 |
| | DUCT INLET | 2129 | 616 | 47 | 405 | 0 | 1513 | 2176 | 47 | 86 | 100 | 1466 | 2362 | 2362 |
| | VALVE INLET | 2080 | 600 | 50 | 392 | ↑ | 1480 | 2130 | 44 | 81 | 100 | 1436 | 2311 | 2311 |
| | ORIFICE INLET | 1959 | 561 | 56 | 361 | \| | 1398 | 2015 | 38 | 66 | 100 | 1360 | 2181 | 2181 |
| | CHAMBER INLET | 1716 | 461 | 40 | 299 | \| | 1255 | 1756 | 33 | 45 | 100 | 1222 | 1901 | 1901 |
| | INJECTOR INLET | 1440 | 347 | 17 | 227 | 0 | 1093 | 1457 | 47 | 42 | 100 | 1046 | 1599 | 1599 |
| OXIDIZER FEED | PUMP INLET | 51 1 | 0 3 | 5 8 | 0 0 | 3 9 | 50 8 | 56 9 | 15 | 85 | 35 | 45 8 | 176 9 | 376 9 |
| | DUCT INLET | 1803 | 492 | 8 | 329 | 0 | 1311 | 1811 | 90 | 81 | 115 | 1221 | 2007 | 2100 |
| | VALVE INLET | 1789 | 486 | 8 | 325 | ↑ | 1303 | 1797 | 89 | 80 | 115 | 1214 | 1992 | 2100 |
| | ORIFICE INLET | 1675 | 439 | 5 | 294 | \| | 1236 | 1680 | 83 | 74 | 115 | 1153 | 1869 | 1869 |
| | DOME INLET | 1675 | 439 | 5 | 294 | \| | 1236 | 1680 | 83 | 74 | 115 | 1153 | 1869 | 1869 |
| | INJECTOR INLET | 1651 | 429 | 5 | 288 | 0 | 1222 | 1656 | 76 | 66 | 115 | 1146 | 1837 | 1837 |
| GAS GENERATOR FUEL FEED | SCOOP INLET | 2118 | 596 | 44 | 409 | 0 | 1522 | 2162 | 48 | 86 | 100 | 1474 | 2348 | 3000 |
| | ORIFICE INLET | 2066 | 564 | 43 | 401 | ↑ | 1502 | 2109 | 57 | 89 | 100 | 1445 | 2298 | 3000 |
| | LINE INLET | 1715 | 786 | 18 | 344 | \| | 929 | 1733 | 41 | 90 | 100 | 888 | 1923 | 3000 |
| | SHUTOFF VALVE INLET | 1589 | 709 | 16 | 324 | \| | 880 | 1605 | 44 | 91 | 100 | 836 | 1796 | 3000 |
| | INJECTOR INLET | 1463 | 632 | 14 | 303 | 0 | 831 | 1477 | 58 | 103 | 100 | 773 | 1680 | 1680 |
| GAS GENERATOR OXIDIZER FEED | SCOOP INLET | 1843 | 505 | 12 | 338 | 0 | 1338 | 1855 | 90 | 81 | 115 | 1248 | 2051 | 3000 |
| | THROTTLE VALVE INLET | 1828 | 496 | 11 | 333 | ↑ | 1332 | 1839 | 89 | 77 | 100 | 1243 | 2016 | 3000 |
| | ORIFICE INLET | 1782 | 450 | 10 | 494 | \| | 1145 | 1792 | 114 | 168 | 100 | 1031 | 2060 | 3000 ① |
| | LINE INLET | 1675 | 749 | 17 | 454 | \| | 926 | 1692 | 84 | 164 | 100 | 842 | 1956 | 3000 |
| | SHUTOFF VALVE INLET | 1598 | 704 | 15 | 425 | \| | 894 | 1613 | 84 | 160 | 100 | 810 | 1873 | 3000 |
| | INJECTOR INLET | 1546 | 673 | 15 | 405 | 0 | 873 | 1561 | 83 | 151 | 100 | 790 | 1812 | 1812 |
| THRUST | CHAMBER, INJECTOR END | 1304 | 291 | 5 | 192 | 0 | 1013 | 1309 | 48 | 34 | 0 | 965 | 1343 | 1343 |
| TURBINE DRIVE | GG CHAMBER, INJECTOR END | 1131 | 428 | 9 | 249 | 0 | 703 | 1140 | 82 | 119 | 100 | 621 | 1359 | 1359 |
| | TURBINE INLET | 1051 | 405 | 8 | 235 | 0 | 646 | 1059 | 86 | 128 | 100 | 560 | 1287 | 1287 |
| TURBINE EXHAUST | FLOW STRAIGHTENER INLET | 71 7 | 26 7 | 0 5 | 15 4 | 0 | 45 0 | 72 2 | 3 4 | 5 1 | 0 | 41 6 | 77 3 | 77 3 |
| | HEAT EXCHANGER INLET | 70 8 | 26 7 | 0 5 | 15 4 | ↑ | 44 1 | 71 3 | 3 4 | 5 1 | 0 | 40 7 | 76 4 | 76 4 |
| | EXH MANIFOLD INLET | 59 6 | 22 1 | 0 4 | 12 8 | \| | 37 5 | 60 0 | 2 8 | 4 3 | 0 | 34 7 | 64 3 | 64 3 |
| | NOZZLE EXT INLET | 34 3 | 12 8 | 0 3 | 7 3 | 0 | 21 5 | 34 6 | 1 6 | 2 4 | 0 | 19 9 | 37 0 | 37 0 |

NOTE: ① MINIMUM EXPECTED VALUE OCCURS WHEN THROTTLING FROM 1650K TO 1350K
ALL VALUES IN PSIA STATIC



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TABLE B-1
INTERNAL OPERATING PARAMETERS
GAS GENERATOR OXIDIZER THROTTLED ENGINE
SHEET 2 OF 9

| SYSTEM | COMPONENT NAME | PARAMETER NAME | PARAMETER UNITS | NOMINAL VALUE | ALTERNATE RATINGS EFFECT MAXIMUM DECREASE | ALTERNATE RATINGS EFFECT MAXIMUM INCREASE | THROTTLING EFFECT MAXIMUM DECREASE | THROTTLING EFFECT MAXIMUM INCREASE | EXPECTED VALUES MINIMUM | EXPECTED VALUES MAXIMUM | RANDOM EFFECTS MAXIMUM DECREASE BELOW EXPECTED MINIMUM | RANDOM EFFECTS MAXIMUM INCREASE ABOVE EXPECTED MAXIMUM | STEADY STATE OPERATING MINIMUM | STEADY STATE OPERATING MAXIMUM |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ENGINE | | THRUST | KIPS | 1800 0 | 450 0 | 0 0 | 300 0 | 0 | 1350 | 1800 | 65 4 | 254 5 | 1284 6 | 2054 5 (1) |
| | | MIXTURE RATIO | | 2 270 | 0 120 | 0 080 | 0 048 | ↕ | 2 150 | 2 350 | 0 291 | 0 134 | 1 859 | 2 484 |
| | | SPECIFIC IMPULSE | SEC | 268 8 | 9 0 | 0 0 | 7 6 | 0 | 258 8 | 268 0 | 6 5 | 38 2 | 252 3 (2) | 306 2 (1) |
| FUEL FEED | PUMP | NET POSITIVE SUCTION HEAD | FT | 128 4 | 0 0 | 0 0 | 0 0 | 0 | 128 4 | 128 4 | 58 4 | 194 9 | 70 0 | 323 3 |
| | | SPEED | RPM | 5809 | 951 | 25 | 633 | ↕ | 4858 | 5834 | 118 | 166 | 4740 | 6000 |
| | | FLOWRATE | GPM | 18,256 | 4422 | 698 | 2449 | ↕ | 13,834 | 18,954 | 447 | 1157 | 13 337 | 20 111 |
| | | HEAD | FT | 6090 | 1807 | 128 | 1192 | ↕ | 4283 | 6218 | 228 | 296 | 4055 | 6514 |
| | | REQUIRED POWER | HP | 30,091 | 13,299 | 65 | 9095 | ↕ | 16,792 | 30,156 | 1245 | 2766 | 15 547 | 32 922 |
| | | TORQUE | FT-LB | 27,205 | 9113 | 221 | 5901 | ↕ | 18,092 | 27,426 | 1190 | 1218 | 16 902 | 28 644 |
| | | FLOW CHARACTERISTICS | GAL/REV | 3 14 | 0 30 | 0 14 | 0 10 | ↕ | 2 84 | 3 28 | 0 06 | 0 15 | 2 78 | 3 43 |
| | | DISCHARGE PRESSURE | PSIA TOTAL | 2178 | 633 | 45 | 418 | ↕ | 1545 | 2223 | 47 | 85 | 1498 | 2318 |
| | DUCTS THRU ORIFICES | FLOWRATE | LB/SEC | 936 | 218 | 40 | 131 | ↕ | 718 | 976 | 33 | 65 | 685 | 1041 |
| | VALVES | PRESSURE DIFFERENTIAL | PSI | 121 | 50 | 10 | 31 | ↕ | 71 | 131 | 7 | 19 | 64 | 150 (3) |
| | ORIFICES | PRESSURE DIFFERENTIAL | PSI | 243 | 141 | 80 | 62 | ↕ | 102 | 323 | 17 | 25 | 85 | 348 |
| | THRUST CHAMBER BODY | FLOWRATE | LB/SEC | 1872 | 436 | 80 | 261 | ↕ | 1436 | 1952 | 65 | 129 | 1371 | 2081 |
| | INJECTOR | FLOWRATE | LB/SEC | 1844 | 436 | 80 | 261 | ↕ | 1448 | 1964 | 65 | 129 | 1382 | 2093 |
| | | PRESSURE DIFFERENTIAL | PSI | 136 | 56 | 12 | 35 | 0 | 80 | 148 | 8 | 21 | 72 | 169 |
| OXIDIZER FEED | PUMP | NET POSITIVE SUCTION HEAD | FT | 103 6 | 0 0 | 0 0 | 0 0 | 0 | 103 6 | 103 6 | 23 6 | 218 8 | 80 0 | 322 4 |
| | | SPEED | RPM | 5809 | 951 | 25 | 633 | ↕ | 4858 | 5834 | 118 | 166 | 4740 | 6000 |
| | | FLOWRATE | GPM | 29,273 | 6941 | 343 | 4387 | ↕ | 22,332 | 29 616 | 913 | 1742 | 21,419 | 31,358 |
| | | HEAD | FT | 3637 | 1049 | 21 | 702 | ↕ | 2588 | 3658 | 138 | 202 | 2450 | 3860 |
| | | REQUIRED POWER | HP | 41,370 | 18,786 | 716 | 12 927 | ↕ | 22,584 | 42,086 | 2592 | 2852 | 19 992 | 44 938 |
| | | TORQUE | FT-LB | 37,402 | 12,874 | 485 | 8542 | ↕ | 24,528 | 37,887 | 2339 | 2340 | 22 189 | 40 227 |
| | | FLOW CHARACTERISTICS | GAL/REV | 5 04 | 0 43 | 0 05 | 0 26 | ↕ | 4 61 | 5 09 | 0 15 | 0 24 | 4 46 | 5 33 |
| | | DISCHARGE PRESSURE | PSIA TOTAL | 1868 | 520 | 10 | 348 | ↕ | 1348 | 1878 | 89 | 81 | 1259 | 1959 |
| | DUCT THRU ORIFICES | FLOWRATE | LB/SEC | 2295 | 541 | 27 | 342 | ↕ | 1754 | 2322 | 151 | 87 | 1603 | 2409 |
| | VALVES | PRESSURE DIFFERENTIAL | PSI | 114 | 47 | 3 | 31 | ↕ | 67 | 117 | 13 | 10 | 54 | 127 (3) |
| | ORIFICES | PRESSURE DIFFERENTIAL | PSI | 0 | 0 | 0 | 0 | ↕ | 0 | 0 | 0 | 0 | 0 | 0 |
| | DOME | FLOWRATE | LB/SEC | 4589 | 1081 | 54 | 684 | ↕ | 3509 | 4643 | 301 | 174 | 3208 | 4817 |
| | INJECTOR | FLOWRATE | LB/SEC | 4584 | 1081 | 54 | 684 | ↕ | 3503 | 4638 | 301 | 174 | 3202 | 4812 |
| | | PRESSURE DIFFERENTIAL | PSI | 347 | 144 | 8 | 96 | 0 | 203 | 355 | 40 | 30 | 163 | 385 |

NOTE:

(1) AMBIENT PRESSURE ACCOUNTS FOR 222K INCREASE AND 33 3 SEC Isp INCREASE
(2) MINIMUM EXPECTED VALUE OCCUR WITH THROTTLE FROM 1650K RATING TO 1350K
(3) AT ENGINE SHUTDOWN VALVE MAY BE SUBJECTED TO TOTAL DISCHARGE PRESSURE UPSTREAM AND ZERO PRESSURE DOWNSTREAM

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# TABLE B-1
## INTERNAL OPERATING PARAMETERS
## GAS GENERATOR OXIDIZER THROTTLED ENGINE
## SHEET 3 OF 9

| SYSTEM | COMPONENT NAME | PARAMETER NAME | PARAMETER UNITS | NOMINAL VALUE | ALTERNATE RATINGS EFFECT MAXIMUM DECREASE | ALTERNATE RATINGS EFFECT MAXIMUM INCREASE | THROTTLING EFFECT MAXIMUM DECREASE | THROTTLING EFFECT MAXIMUM INCREASE | EXPECTED VALUES MINIMUM | EXPECTED VALUES MAXIMUM | RANDOM EFFECTS MAXIMUM DECREASE BELOW EXPECTED MINIMUM | RANDOM EFFECTS MAXIMUM INCREASE ABOVE EXPECTED MAXIMUM | STEADY STATE OPERATING MINIMUM | STEADY STATE OPERATING MAXIMUM |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| GG FUEL FEED | BLEED | PRESSURE | PSIA TOTAL | 2178 | 633 | 45 | 417 | 0 | 1545 | 2223 | 47 | 86 | 1498 | 2319 |
| | SCOOP THROUGH INJECTOR | FLOWRATE | LB/SEC | 163 8 | 61 9 | 1 3 | 13 8 | | 101 9 | 165 1 | 6 7 | 13 2 | 95 2 | 178 3 |
| | ORIFICE | PRESSURE DIFFERENTIAL | PSI | 351 | 44 | 269 | 82 ① | | 294 ① | 620 | 39 | 100 | 255 | 720 |
| | SHUTOFF VALVE | PRESSURE DIFFERENTIAL | PSI | 126 | 77 | 2 | 21 | | 49 | 128 | 7 | 23 | 42 | 151 ② |
| | INJECTORS | PRESSURE DIFFERENTIAL | PSI | 393 | 241 | 6 | 64 | 0 | 152 | 399 | 22 | 72 | 130 | 471 |
| GG OXIDIZER FEED | BLEED | PRESSURE | PSIA TOTAL | 1868 | 520 | 10 | 348 | 0 | 1348 | 1878 | 89 | 81 | 1259 | 1959 |
| | SCOOP THROUGH INJECTOR | FLOWRATE | LB/SEC | 66 1 | 23 8 | 0 4 | 13 9 | 0 | 42 3 | 66 5 | 3 2 | 4 1 | 39 1 | 70 6 |
| | THROTTLE VALVE | PRESSURE DIFFERENTIAL | PSI | 46 | 27 | 1 | 0 | 161 | 19 | 207 | 3 | 29 | 16 | 236 |
| | ORIFICE | PRESSURE DIFFERENTIAL | PSI | 107 | 7 | 283 | 93 ① | 0 | 67 ① | 390 | 10 | 49 | 57 | 439 |
| | SHUTOFF VALVE | PRESSURE DIFFERENTIAL | PSI | 52 | 31 | 0 | 20 | | 21 | 52 | 4 | 7 | 17 | 55 ② |
| | INJECTOR | PRESSURE DIFFERENTIAL | PSI | 439 | 259 | 6 | 165 | 0 | 180 | 445 | 35 | 62 | 145 | 507 |
| THRUST | CHAMBER | FLOWRATE | LB/SEC | 6468 | 1417 | 6 | 945 | 0 | 5051 | 6474 | 270 | 179 | 4781 | 6653 |
| | | MIXTURE RATIO | | 2 433 | 0 168 | 0 093 | 0 037 | | 2 265 | 2 526 | 0 315 | 0 148 | 1 950 | 2 674 |
| | | THROAT PRESSURE | PSIA TOTAL | 1138 | 254 | 4 | 168 | 0 | 884 | 1142 | 42 | 30 | 842 | 1172 |
| TURBINE DRIVE | GG AND TURBINE GAS GENERATOR | FLOWRATE | LB/SEC | 229 9 | 85 1 | 1 7 | 27 7 | 0 | 144 8 | 231 6 | 8 8 | 15 5 | 136 0 | 247 1 |
| | | MIXTURE RATIO | - | 0 403 | 0 000 | 0 012 | 0 059 | | 0 344 | 0 415 | 0 036 | 0 023 | 0 305 | 0 438 |
| | | EXHAUST TEMPERATURE | F | 1427 | 0 | 0 | 204 | | 1223 | 1427 | 110 | 79 | 1113 | 1506 |
| | TURBINE | INLET TEMPERATURE (MANIFOLD) | F | 1500 | 0 | 0 | 335 | | 1165 | 1500 | 110 | 175 | 1055 | 1675 |
| | | SPEED | RPM | 5809 | 951 | 25 | 633 | | 4858 | 5834 | 118 | 166 | 4740 | 6000 |
| | | TORQUE | FT-LB | 64,609 | 21,440 | 364 | 16,707 | | 40,364 | 64,973 | 2823 | 2812 | 37,541 | 67 785 |
| | | POWER | HP | 71 461 | 31,792 | 711 | 22,023 | | 39,669 | 72 171 | 3424 | 4875 | 36 245 | 77 046 |
| | | THROAT PRESSURE | PSIA TOTAL | 1072 | 406 | 8 | 235 | | 666 | 1080 | 87 | 128 | 579 | 1208 |
| | | PRESSURE RATIO | - | 14 96 | 0 14 | 0 000 | 0 08 | 0 | 14 82 | 14 96 | 2 43 | 2 38 | 12 39 | 17 34 |
| TURBINE EXHAUST | FLOW STRAIGHTENER THROUGH EXT | FLOWRATE | LB/SEC | 229 9 | 85 1 | 1 7 | 27 7 | 0 | 144 8 | 231 6 | 8 8 | 15 5 | 136 0 | 247 1 |
| | FLOW STRAIGHTENER INLET | TEMPERATURE | F | 1132 | 29 | 1 | 145 | | 987 | 1133 | 92 | 167 | 920 | 1300 |
| | HEAT EXCHANGER INLET | TEMPERATURE | F | 1132 | 29 | 1 | 145 | | 987 | 1133 | 92 | 167 | 920 | 1300 |
| | EXHAUST MANIFOLD INLET | TEMPERATURE | F | 1057 | 29 | 1 | 145 | | 912 | 1058 | 92 | 242 | 846 | 1300 |
| | NOZZLE EXTENSION | TEMPERATURE | F | 1057 | 29 | 1 | 145 | | 912 | 1058 | 92 | 242 | 846 | 1300 |
| | | THROAT PRESSURE | PSIA TOTAL | 43 6 | 16 3 | 0 3 | 9 3 | 0 | 27 3 | 43 9 | 1 6 | 2 4 | 25 7 | 46 3 |

NOTE: ① THROTTLING EFFECT MAXIMUM DECREASE APPLICABLE THROTTLE FROM 1650K TO 1350K. EXPECTED MINIMUM OCCURS WITH THROTTLE FROM 1800K TO 1500K

② AT ENGINE SHUTDOWN VALVE MAY BE SUBJECTED TO MAXIMUM VALVE INLET PRESSURE (OPERATING PLUS SURGE) AT INLET AND ZERO PRESSURE AT OUTLET

③ MINIMUM OCCURS WITH THROTTLE FROM 1650K TO 1350K.

TABLE B-1
INTERNAL OPERATING PRESSURE ENVIRONMENT
CALIBRATED ORIFICED ENGINE
SHEET 4 OF 9

| SYSTEM | COMPONENT NAME | NOMINAL VALUE | ALTERNATE RATINGS EFFECT | | EXPECTED VALUES | | INDEPENDENT VARIABLE VARIATION EFFECT | | CALIBRATION AND RANDOM HARDWARE UNCERTAINTY | | MAXIMUM OSCILLATIONS | STEADY STATE OPERATING | | MAXIMUM OPERATING INCLUDING SURGE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | MAXIMUM DECREASE | MAXIMUM INCREASE | MINIMUM | MAXIMUM | MAXIMUM DECREASE BELOW EXPECTED MINIMUM | MAXIMUM INCREASE ABOVE EXPECTED MAXIMUM | MAXIMUM DECREASE BELOW EXPECTED MINIMUM | MAXIMUM INCREASE ABOVE EXPECTED MAXIMUM | | MINIMUM | MAXIMUM | |
| FUEL FEED | PUMP INLET | TBD | TBD | TBD | 41 1 | TBD | 20 0 | TBD | 0 0 | TBD | 45 | 21 1 | TBD | TBD |
| | DUCT INLET | ↑ | ↑ | ↑ | 1513 | ↑ | 32 | ↑ | 94 | ↑ | 100 | 1387 | ↑ | ↑ |
| | VALVE INLET | | | | 1480 | | 33 | | 94 | | 100 | 1353 | | |
| | ORIFICE INLET | | | | 1398 | | 36 | | 95 | | 100 | 1267 | | |
| | CHAMBER INLET | | | | 1255 | | 43 | | 63 | | 100 | 1149 | | |
| | INJECTOR INLET | | | | 1093 | | 50 | | 36 | | 100 | 1007 | | |
| OXIDIZER FEED | PUMP INLET | | | | 50 8 | | 15 0 | | 0 0 | | 35 | 35 8 | | |
| | DUCT INLET | | | | 1311 | | 104 | | 74 | | 115 | 1133 | | |
| | VALVE INLET | | | | 1303 | | 101 | | 73 | | 115 | 1129 | | |
| | ORIFICE INLET | | | | 1236 | | 90 | | 70 | | 115 | 1076 | | |
| | DOME INLET | | | | 1236 | | 90 | | 70 | | 115 | 1076 | | |
| | INJECTOR INLET | | | | 1222 | | 87 | | 61 | | 115 | 1074 | | |
| GG FUEL FEED | SCOOP INLET | | | | | | | | 94 | | 100 | 1302 | | |
| | ORIFICE INLET | | | | 1502 | | 126 | | 90 | | 100 | 1286 | | |
| | LINE INLET | | | | 929 | | 40 | | 137 | | 100 | 752 | | |
| | SHUTOFF VALVE INLET | | | | 880 | | 41 | | 120 | | 100 | 719 | | |
| | INJECTOR INLET | | | | 831 | | 42 | | 96 | | 100 | 693 | | |
| GG OXIDIZER FEED | SCOOP INLET | | | | 1338 | | 109 | | 74 | | 100 | 1155 | | |
| | ORIFICE INLET | | | | 1332 | | 108 | | 70 | | 100 | 1154 | | |
| | LINE INLET | | | | 926 | | 68 | | 116 | | 100 | 742 | | |
| | SHUTOFF VALVE INLET | | | | 894 | | 64 | | 111 | | 100 | 719 | | |
| | INJECTOR INLET | | | | 873 | | 62 | | 101 | | 100 | 710 | | |
| THRUST | CHAMBER, INJECTOR END | | | | | | | | 27 | | 0 | 933 | | |
| TURBINE DRIVE | GG CHAMBER INJECTOR END | | | | 703 | | 45 | | 60 | | 100 | 598 | | |
| | TURBINE INLET | | | | 646 | | 43 | | 57 | | 100 | 546 | | |
| TURBINE EXHAUST | FLOW STRAIGHTENER INLET | | | | 45 0 | | 2 6 | | 4 2 | | 0 | 38 2 | | |
| | HEAT EXCHANGER INLET | | | | 44 1 | | 2 6 | | 4 2 | | 0 | 37 3 | | |
| | EXHAUST MANIFOLD INLET | | | | 37 5 | | 2 3 | | 3 7 | | 0 | 31 5 | | |
| | NOZZLE EXTENSION INLET | TBD | TBD | TBD | 21 5 | TBD | 1 3 | TBD | 2 1 | TBD | 0 | 18 1 | TBD | TBD |

NOTE: ALL VALUES IN PSIA STATIC



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# TABLE B-1
## INTERNAL OPERATING PARAMETERS
## CALIBRATED ORIFICED ENGINE
## SHEET 5 OF 9

| SYSTEM | COMPONENT NAME | PARAMETER NAME | PARAMETER UNITS | NOMINAL VALUE | ALTERNATE RATINGS EFFECT: MAXIMUM DECREASE | ALTERNATE RATINGS EFFECT: MAXIMUM INCREASE | EXPECTED VALUES: MINIMUM | EXPECTED VALUES: MAXIMUM | INDEPENDENT VARIABLE VARIATION EFFECT: MAXIMUM DECREASE BELOW EXPECTED MINIMUM | INDEPENDENT VARIABLE VARIATION EFFECT: MAXIMUM INCREASE ABOVE EXPECTED MAXIMUM | CALIBRATION AND RANDOM HARDWARE UNCERTAINTY: MAXIMUM DECREASE BELOW EXPECTED MINIMUM | CALIBRATION AND RANDOM HARDWARE UNCERTAINTY: MAXIMUM INCREASE ABOVE EXPECTED MAXIMUM | STEADY STATE OPERATING: MINIMUM | STEADY STATE OPERATING: MAXIMUM |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ENGINE | | THRUST | KIPS | TBD | TBD | TBD | 1350 0 | TBD | 96 8 | TBD | 34 8 | TBD | 1218 4 | TBD |
| | | MIXTURE RATIO | | | | | 2 150 | | 0 228 | | 0 064 | | 1 858 | |
| | | SPECIFIC IMPULSE | SEC | | | | 259 8 | | 5 4 | | 4 0 | | 250 4 | |
| FUEL FEED | PUMP | NET POSITIVE SUCTION HEAD | FT | | | | 128 4 | | 58 4 | | 0 0 | | 70 0 | |
| | | SPEED | RPM | | | | 4858 | | 185 | | 132 | | 4541 | |
| | | FLOWRATE | GPM | | | | 13,834 | | 24 | | 480 | | 13 330 | |
| | | HEAD | FT | | | | 4283 | | 380 | | 264 | | 3639 | |
| | | REQUIRED POWER | HP | | | | 16,792 | | 1211 | | 3743 | | 14 137 | |
| | | TORQUE | FT-LB | | | | 18,092 | | 637 | | 1940 | | 16 074 | |
| | | FLOW CHARACTERISTIC $(\frac{Q}{N})$ | GAL/REV | | | | 2 84 | | 0 01 | | 0 07 | | 2 74 | |
| | | DISCHARGE PRESSURE | PSIA TOTAL | | | | 1545 | | 40 | | 93 | | 1412 | |
| | DUCTS THROUGH ORIFICES | FLOWRATE | LB/SEC | | | | 718 | | 0 | | 17 | | 693 | ⊖ |
| | VALVES | PRESSURE DIFFERENTIAL | PSI | | | | 71 | | 0 | | 4 | | 65 | |
| | ORIFICES | PRESSURE DIFFERENTIAL | PSI | | | | 102 | | 0 | | 9 | | 10 | |
| | THRUST CHAMBER BODY | FLOWRATE | LB/SEC | | | | 1436 | | 0 | | 33 | | 1386 | |
| | INJECTOR | FLOWRATE | LB/SEC | | | | 1448 | | 0 | | 33 | | 1398 | |
| | | PRESSURE DIFFERENTIAL | PSI | | | | 80 | | 0 | | 5 | | 74 | |
| OXIDIZER FEED | PUMP | NET POSITIVE SUCTION HEAD | FT | | | | 103 6 | | 23 6 | | 0 0 | | 80 | |
| | | SPEED | RPM | | | | 4858 | | 185 | | 132 | | 4541 | |
| | | FLOWRATE | GPM | | | | 22,332 | | 1660 | | 670 | | 20 002 | |
| | | HEAD | FT | | | | 2588 | | 153 | | 146 | | 2289 | |
| | | REQUIRED POWER | HP | | | | 22,584 | | 3079 | | 1971 | | 17,534 | |
| | | TORQUE | FT-LB | | | | 24,528 | | 2471 | | 1934 | | 20,123 | |
| | | FLOW CHARACTERISTIC $(\frac{Q}{N})$ | GAL/REV | | | | 4 61 | | 0 17 | | 0 09 | | 4 35 | |
| | | DISCHARGE PRESSURE | PSIA TOTAL | | | | 1348 | | 104 | | 73 | | 1171 | |
| | DUCTS THROUGH ORIFICES | FLOWRATE | LB/SEC | | | | 1754 | | 149 | | 52 | | 1553 | |
| | VALVES | PRESSURE DIFFERENTIAL | PSI | | | | 67 | | 11 | | 5 | | 51 | ⊖ |
| | ORIFICES | PRESSURE DIFFERENTIAL | PSI | | | | 0 | | 0 | | 0 | | 0 | |
| | DOME | FLOWRATE | LB/SEC | | | | 3509 | | 298 | | 104 | | 3107 | |
| | INJECTOR | FLOWRATE | LB/SEC | | | | 3503 | | 298 | | 104 | | 3101 | |
| | | PRESSURE DIFFERENTIAL | PSI | TBD | TBD | TBD | 203 | TBD | 34 | TBD | 14 | TBD | 155 | TBD |

NOTE: ⊖ AT ENGINE SHUTDOWN VALVE MAY BE SUBJECTED TO MAXIMUM VALVE INLET PRESSURE (OPERATING PLUS SURGE) AT INLET AND ZERO AT OUTLET



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# TABLE B-1
## INTERNAL OPERATING PARAMETERS
## CALIBRATED ORIFICED ENGINE
## SHEET 6 OF 9

| SYSTEM | COMPONENT NAME | PARAMETER NAME | PARAMETER UNITS | NOMINAL VALUE | ALTERNATE RATINGS EFFECT: MAXIMUM DECREASE | ALTERNATE RATINGS EFFECT: MAXIMUM INCREASE | EXPECTED VALUES: MINIMUM | EXPECTED VALUES: MAXIMUM | INDEPENDENT VARIABLE VARIATION EFFECT: MAXIMUM DECREASE BELOW EXPECTED MINIMUM | INDEPENDENT VARIABLE VARIATION EFFECT: MAXIMUM INCREASE ABOVE EXPECTED MAXIMUM | CALIBRATION AND RANDOM HARDWARE UNCERTAINTY: MAXIMUM DECREASE BELOW EXPECTED MINIMUM | CALIBRATION AND RANDOM HARDWARE UNCERTAINTY: MAXIMUM INCREASE ABOVE EXPECTED MAXIMUM | STEADY STATE OPERATING: MINIMUM | STEADY STATE OPERATING: MAXIMUM |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| GG FUEL FEED | BLEED | PRESSURE | PSIA TOTAL | TBD | TBD | TBD | 1545 | TBD | 40 | TBD | 93 | TBD | 1412 | TBD |
| | SCOOP THROUGH INJECTOR | FLOWRATE | LB/SEC | | | | 101 9 | | 0 0 | | 9 5 | | 92 4 | |
| | ORIFICE | PRESSURE DIFFERENTIAL | PSI | | | | 307 | | 0 | | 224 | | 83 | |
| | SHUTOFF VALVE | PRESSURE DIFFERENTIAL | PSI | | | | 49 | | 0 | | 10 | | 39 | ① |
| | INJECTOR | PRESSURE DIFFERENTIAL | PSI | | | | 152 | | 0 | | 32 | | 120 | |
| GG OXIDIZER FEED | BLEED | PRESSURE | PSIA TOTAL | | | | 1348 | | 104 | | 73 | | 1171 | |
| | SCOOP THROUGH INJECTOR | FLOWRATE | LB/SEC | | | | 42 3 | | 2 2 | | 3 3 | | 36 8 | |
| | ORIFICE | PRESSURE DIFFERENTIAL | PSI | | | | 146 | | 40 | | 153 | | 0 0 | |
| | SHUTOFF VALVE | PRESSURE DIFFERENTIAL | PSI | | | | 21 | | 2 | | 4 | | 15 | ① |
| | INJECTOR | PRESSURE DIFFERENTIAL | PSI | | | | 180 | | 18 | | 32 | | 131 | |
| THRUST | CHAMBER | FLOWRATE | LB/SEC | | | | 5051 | | 269 | | 137 | | 4645 | |
| | | MIXTURE RATIO | | | | | 2 265 | | 0 243 | | 0 075 | | 1 947 | |
| | | THRUST PRESSURE | PSIA TOTAL | | | | 884 | | 46 | | 23 | | 815 | |
| TURBINE DRIVE | GAS GENERATOR AND TURBINE | FLOWRATE | LB/SEC | | | | 144 8 | | 1 0 | | 12 6 | | 131 2 | |
| | GAS GENERATOR | MIXTURE RATIO | | | | | 0 403 | | 0 026 | | 0 015 | | 0 362 | |
| | | EXHAUST TEMPERATURE | F | | | | 1427 | | 98 | | 36 | | 1293 | |
| | TURBINE | INLET TEMPERATURE (MANIFOLD) | F | | | | 1500 | | 180 | | | | 1320 | |
| | | SPEED | RPM | | | | 4858 | | 185 | | 132 | | 4541 | |
| | | TORQUE | FT-LB | | | | 43,169 | | 3108 | | 2461 | | 37 600 | |
| | | POWER | HP | | | | 39,667 | | 4290 | | 3275 | | 32,104 | |
| | | THROAT PRESSURE | PSIA TOTAL | | | | 666 | | 43 | | 57 | | 566 | |
| | | PRESSURE RATIO | | | | | 14 82 | | 0 00 | | 0 72 | | 14 10 | |
| TURBINE EXHAUST | FLOW STRAIGHTENER EXTENSION | FLOWRATE | LB/SEC | | | | 144 8 | | 1 0 | | 12 6 | | 131 2 | |
| | FLOW STRAIGHTENER INLET | TEMPERATURE | F | | | | 1103 | | 74 | | 32 | | 997 | |
| | HEAT EXCHANGER INLET | TEMPERATURE | F | | | | 1103 | | 74 | | 32 | | 997 | |
| | EXHAUST MANIFOLD INLET | TEMPERATURE | F | | | | 1028 | | 74 | | 32 | | 922 | |
| | NOZZLE EXTENSION | TEMPERATURE | F | | | | 1028 | | 74 | | 32 | | 922 | |
| | | THROAT PRESSURE | PSIA TOTAL | TBD | TBD | TBD | 27 3 | TBD | 1 7 | TBD | 2 5 | TBD | 23 1 | TBD |

NOTE: ① AT ENGINE SHUTDOWN VALVE MAY BE SUBJECTED TO MAXIMUM VALVE INLET PRESSURE (OPERATING PLUS SURGE) AT INLET AND ZERO AT OUTLET

TABLE B-1
INTERNAL OPERATING PRESSURE ENVIRONMENT
UNCALIBRATED ORIFICED ENGINE
SHEET 7 OF 9

| SYSTEM | COMPONENT NAME | NOMINAL VALUE | ACCEPTANCE TEST EXPECTED VALUE | ALTERNATE RATING EFFECT | | EXPECTED VALUES | | RANDOM EFFECTS | | MAXIMUM OSCIL-LATIONS | STEADY STATE OPERATING | | MAXIMUM OPERATING INCLUDING SURGE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | MAXIMUM DECREASE | MAXIMUM INCREASE | MINIMUM | MAXIMUM | MAXIMUM DECREASE BELOW EXPECTED MINIMUM | MAXIMUM INCREASE ABOVE EXPECTED MAXIMUM | | MINIMUM | MAXIMUM | |
| FUEL FEED | PUMP INLET | TBD | TBD | TBD | TBD | 41 1 | TBD | 4 0 | TBD | 45 | 37 1 | TBD | TBD |
| | DUCT INLET | ↑ | ↑ | ↑ | ↑ | 1517 | ↑ | 119 | ↑ | 100 | 1398 | ↑ | ↑ |
| | VALVE INLET | | | | | 1484 | | 116 | | 100 | 1368 | | |
| | ORIFICE INLET | | | | | 1401 | | 108 | | 100 | 1293 | | |
| | CHAMBER INLET | | | | | 1257 | | 90 | | 100 | 1167 | | |
| | INJECTOR INLET | | | | | 1094 | | 66 | | 100 | 1028 | | |
| OXIDIZER FEED | PUMP INLET | | | | | 50 8 | | 7 0 | | 35 | 43 8 | | |
| | DUCT INLET | | | | | 1315 | | 108 | | 115 | 1207 | | |
| | VALVE INLET | | | | | 1307 | | 107 | | 115 | 1200 | | |
| | ORIFICE INLET | | | | | 1239 | | 98 | | 115 | 1141 | | |
| | DOME INLET | | | | | 1239 | | 98 | | 115 | 1141 | | |
| | INJECTOR INLET | | | | | 1224 | | 89 | | 115 | 1135 | | |
| GG FUEL FEED | SCOOP INLET | | | | | 1527 | | 120 | | 100 | 1407 | | |
| | ORIFICE INLET | | | | | 1506 | | 116 | | 100 | 1390 | | |
| | LINE INLET | | | | | 932 | | 76 | | 100 | 856 | | |
| | SHUTOFF VALVE INLET | | | | | 883 | | 72 | | 100 | 811 | | |
| | INJECTOR INLET | | | | | 834 | | 62 | | 100 | 772 | | |
| GG OXIDIZER FEED | SCOOP INLET | | | | | 1343 | | 108 | | 115 | 1235 | | |
| | ORIFICE INLET | | | | | 1336 | | 102 | | 100 | 1234 | | |
| | LINE INLET | | | | | 930 | | 76 | | 100] | 854 | | |
| | SHUTOFF VALVE INLET | | | | | 897 | | 71 | | 100] | 826 | | |
| | INJECTOR INLET | | | | | 876 | | 62 | | 100 | 814 | | |
| THRUST | CHAMBER, INJECTOR END | | | | | 1014 | | 56 | | 0 | 958 | | |
| TURBINE DRIVE | GG CHAMBER, INJECTOR END | | | | | 705 | | 54 | | 100 | 651 | | |
| | TURBINE INLET | | | | | 648 | | 54 | | 100 | 594 | | |
| TURBINE EXHAUST | FLOW STRAIGHTENER INLET | | | | | 45 1 | | 3 7 | | 0 | 41 4 | | |
| | HEAT EXCHANGER INLET | | | | | 44 2 | | 3 7 | | 0 | 40 5 | | |
| | EXHAUST MANIFOLD INLET | | | | | 37 6 | | 3 1 | | 0 | 34 5 | | |
| | NOZZLE EXTENSION INLET | TBD | TBD | TBD | TBD | 21 5 | TBD | 1 8 | TBD | 0 | 19 7 | TBD | TBD |

NOTE: ALL VALUES IN PSIA STATIC



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TABLE B-1
INTERNAL OPERATING PARAMETERS
UNCALIBRATED ORIFICED ENGINE
SHEET 8 OF 9

| SYSTEM | COMPONENT NAME | PARAMETER NAME | PARAMETER UNITS | NOMINAL VALUE | ACCEPTANCE TEST EXPECTED VALUE | ALTERNATE RATINGS EFFECT MAXIMUM DECREASE | ALTERNATE RATINGS EFFECT MAXIMUM INCREASE | EXPECTED VALUES MINIMUM | EXPECTED VALUES MAXIMUM | RANDOM EFFECTS MAXIMUM DECREASE BELOW EXPECTED MINIMUM | RANDOM EFFECTS MAXIMUM INCREASE ABOVE EXPECTED MAXIMUM | STEADY STATE OPERATING MINIMUM | STEADY STATE OPERATING MAXIMUM |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ENGINE | | THRUST | KIPS | TBD | TBD | TBD | TBD | 1376 1 | TBD | 86 9 | TBD | 1289 2 | TBD |
| | | MIXTURE RATIO | | | | | | 2 154 | | 0 098 | | 2 056 | |
| | | SPECIFIC IMPULSE | SEC | | | | | 263 6 | | 3 6 | | 260 0 | |
| FUEL FEED | PUMP | NET POSITIVE SUCTION HEAD | FT | | | | | 128 9 | | 11 8 | | 117 1 | |
| | | SPEED | RPM | | | | | 4871 | | 210 | | 4661 | |
| | | FLOWRATE | GPM | | | | | 13,891 | | 801 | | 13,090 | |
| | | HEAD | FT | | | | | 4310 | | 356 | | 3954 | |
| | | REQUIRED POWER | HP | | | | | 16 893 | | 2172 | | 14 726 | |
| | | TORQUE | FT-LB | | | | | 18,127 | | 2076 | | 16,051 | |
| | | FLOW CHARACTERISTIC ($\frac{Q}{N}$) | GAL/REV | | | | | 2 84 | | 0 05 | | 2 79 | |
| | | DISCHARGE PRESSURE | PSIA TOTAL | | | | | 1547 | | 119 | | 1428 | |
| | DUCTS THROUGH ORIFICES | FLOWRATE | LB/SEC | | | | | 718 | | 43 | | 675 | |
| | VALVES | PRESSURE DIFFERENTIAL | PSI | | | | | 72 | | 10 | | 62 | ① |
| | ORIFICES | PRESSURE DIFFERENTIAL | PSI | | | | | 103 | | 20 | | 83 | |
| | THRUST CHAMBER BODY | FLOWRATE | LB/SEC | | | | | 1435 | | 85 | | 1350 | |
| | INJECTOR | FLOWRATE | LB/SEC | | | | | 1447 | | 85 | | 1362 | |
| | | PRESSURE DIFFERENTIAL | PSI | | | | | 80 | | 11 | | 69 | |
| OXIDIZER FEED | PUMP | NET POSITIVE SUCTION HEAD | FT | | | | | 103 9 | | 14 2 | | 89 7 | |
| | | SPEED | RPM | | | | | 4 871 | | 210 | | 4661 | |
| | | FLOWRATE | GPM | | | | | 22,426 | | 1358 | | 21 068 | |
| | | HEAD | FT | | | | | 2603 | | 213 | | 2390 | |
| | | REQUIRED POWER | HP | | | | | 22,781 | | 3115 | | 19,666 | |
| | | TORQUE | FT-LB | | | | | 24,623 | | 3056 | | 21,567 | |
| | | FLOW CHARACTERISTIC ($\frac{Q}{N}$) | GAL/REV | | | | | 4 61 | | 0 11 | | 4 50 | |
| | | DISCHARGE PRESSURE | PSIA TOTAL | | | | | 1351 | | 107 | | 1244 | |
| | DUCTS THROUGH ORIFICES | FLOWRATE | LB/SEC | | | | | 1755 | | 107 | | 1648 | |
| | VALVES | PRESSURE DIFFERENTIAL | PSI | | | | | 68 | | 7 | | 61 | ① |
| | ORIFICES | PRESSURE DIFFERENTIAL | PSI | | | | | 0 | | 0 | | 0 | |
| | DOME | FLOWRATE | LB/SEC | | | | | 3512 | | 213 | | 3299 | |
| | INJECTOR | FLOWRATE | LB/SEC | | | | | 3506 | | 213 | | 3293 | |
| | | PRESSURE DIFFERENTIAL | PSI | TBD | TBD | TBD | TBD | 204 | TBD | 22 | TBD | 182 | TBD |

NOTE ① AT ENGINE SHUTDOWN VALVE MAY BE SUBJECTED TO MAXIMUM VALVE INERT PRESSURE (OPERATING PLUS SURGE) AT INLET AND ZERO AT OUTLET

# TABLE B-1
## INTERNAL OPERATING PARAMETERS
## UNCALIBRATED ORIFICED ENGINE
## SHEET 9 OF 9

| SYSTEM | COMPONENT NAME | PARAMETER NAME | PARAMETER UNITS | NOMINAL VALUE | ACCEPTANCE TEST EXPECTED VALUE | ALTERNATE RATINGS EFFECT: MAXIMUM DECREASE | ALTERNATE RATINGS EFFECT: MAXIMUM INCREASE | EXPECTED VALUES: MINIMUM | EXPECTED VALUES: MAXIMUM | RANDOM EFFECTS: MAXIMUM DECREASE BELOW EXPECTED MINIMUM | RANDOM EFFECTS: MAXIMUM INCREASE ABOVE EXPECTED MAXIMUM | STEADY STATE OPERATING: MINIMUM | STEADY STATE OPERATING: MAXIMUM |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| GG FUEL FEED | BLEED | PRESSURE | PSIA TOTAL | TBD | TBD | TBD | TBD | 1547 | TBD | 119 | TBD | 1428 | TBD |
| | SCOOP THROUGH INJECTOR | FLOWRATE | LB/SEC | | | | | 101 8 | | 6 4 | | 95 4 | |
| | ORIFICE | PRESSURE DIFFERENTIAL | PSI | | | | | 308 | | 44 | | 264 | |
| | SHUTOFF VALVE | PRESSURE DIFFERENTIAL | PSI | | | | | 49 | | 7 | | 42 | ① |
| | INJECTOR | PRESSURE DIFFERENTIAL | PSI | | | | | 153 | | 22 | | 131 | |
| GG OXIDIZER FEED | BLEED | PRESSURE | PSIA TOTAL | | | | | 1351 | | 107 | | 1244 | |
| | SCOOP THROUGH INJECTOR | FLOWRATE | LB/SEC | | | | | 42 2 | | 3 8 | | 38 4 | |
| | ORIFICE | PRESSURE DIFFERENTIAL | PSI | | | | | 146 | | 27 | | 119 | |
| | SHUTOFF VALVE | PRESSURE DIFFERENTIAL | PSI | | | | | 21 | | 4 | | 17 | ① |
| | INJECTOR | PRESSURE DIFFERENTIAL | PSI | | | | | 180 | | 37 | | 143 | |
| THRUST | CHAMBER | FLOWRATE | LB/SEC | | | | | 5052 | | 280 | | 4772 | |
| | | MIXTURE RATIO | | | | | | 2 268 | | 0 106 | | 2 162 | |
| | | THRUST PRESSURE | PSIA TOTAL | | | | | 884 | | 49 | | 835 | |
| TURBINE DRIVE | GAS GENERATOR AND TURBINE | FLOWRATE | LB/SEC | | | | | 144 6 | | 9 8 | | 134 8 | |
| | GAS GENERATOR | MIXTURE RATIO | | | | | | 0 403 | | 0 022 | | 0 381 | |
| | TURBINE | EXHAUST TEMPERATURE | F | | | | | 1432 | | 71 | | 1361 | |
| | | INLET TEMPERATURE (MANIFOLD) | F | | | | | 1509 | | 134 | | 1375 | |
| | | SPEED | RPM | | | | | 4871 | | 210 | | 4661 | |
| | | TORQUE | FT-LB | | | | | 43,294 | | 3796 | | 39,498 | |
| | | POWER | HP | | | | | 39 972 | | 5218 | | 34 754 | |
| | | THROAT PRESSURE | PSIA TOTAL | | | | | 668 | | 54 | | 614 | |
| | | PRESSURE RATIO | | | | | | 14 82 | | 1 46 | | 13 36 | |
| TURBINE EXHAUST | FLOW STRAIGHTENER THROUGH EXTENSION | FLOWRATE | LB/SEC | | | | | 144 6 | | 9 8 | | 134 8 | |
| | FLOW STRAIGHTENER INLET | TEMPERATURE | F | | | | | 1106 | | 54 | | 1052 | |
| | HEAT EXCHANGER INLET | TEMPERATURE | F | | | | | 1106 | | 54 | | 1052 | |
| | EXHAUST MANIFOLD INLET | TEMPERATURE | F | | | | | 1031 | | 54 | | 977 | |
| | NOZZLE EXTENSION | TEMPERATURE | F | | | | | 1031 | | 54 | | 977 | |
| | | THROAT PRESSURE | PSIA TOTAL | TBD | TBD | TBD | TBD | 27 4 | TBD | 2 3 | TBD | 25 1 | TBD |

NOTE: ① AT ENGINE SHUTDOWN VALVE MAY BE SUBJECTED TO MAXIMUM VALVE INLET PRESSURE (OPERATING PLUS SURGE AT INLET AND ZERO AT OUTLET



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3.1.1.2.1 THRUST SYSTEM - The function of the thrust system shall be to receive, mix, combust and exhaust the propellants, supplied from the fuel and oxidizer feed systems, to provide the axial thrust required by paragraph 3.1.1.1 Primary Performance Characteristics. The primary components of the thrust system shall include; the thrust chamber body, the thrust chamber nozzle extension, the thrust chamber injector, the oxidizer dome, and the gimbal assembly. Detailed quantitative thrust system characteristics are tabulated in Tables B-1 and C-1.

TABLE C-1

THRUST SYSTEM CHARACTERISTICS

| COMPONENT | PARAMETER NAME | SYMBOL | UNITS | RATINGS NOMINAL | MINIMUM | MAXIMUM |
|---|---|---|---|---|---|---|
| Chamber | Characteristic Velocity Ratio[11] | $\eta C^*$ | - | 0.935 | 0.930 | 0.950 |
| | Contraction Ratio | $\chi$ | - | 1.25 | 1.20 | 1.30 |
| Nozzle | Effective Throat Area | At | $in^2$ | 960.0 | 955.0 | 965.0 |
| | Expansion Ratio | $\epsilon$ | - | 15.725 | 15.600 | 15.850 |
| | Thrust Coefficient Ratio[12] | $\eta C_f$ | - | 1.0445 | 1.0350 | 1.0550 |

[11]Ratio of effective characteristic velocity to theoritical characteristic velocity

[12]Ratio of effective thrust coefficient to theoritical thrust coefficient

3.1.1.2.1.1 FLUIDS HANDLED - The thrust system shall utilize liquid oxygen and RP-1 as propellants for operation. Liquid oxygen and RP-1/RJ-1 shall be used, with hypergolic fluid to provide an ignition source, to establish thrust chamber ignition. Turbine exhaust products shall be injected into the thrust system. The thrust system shall also be compatible with trichloroethylene, gaseous nitrogen, and water.

3.1.1.2.1.2 FLUID FLOWRATES - The estimated nominal fluid flowrates shall be approximately 4600 lb/sec oxidizer, 1900 lb/sec fuel and 225 lb/sec exhaust products. The detailed quantitative characteristics are tabulated in Tables B-1 and C-1.

3.1.1.2.1.3 FLUID PRESSURES - The thrust chamber shall exhaust to ambient pressure during operation. The detailed quantitative characteristics are tabulated in Tables B-1 and C-1. The thrust system shall be designed for the following pressure criteria.

a. STRUCTURAL DESIGN CRITERIA - The design pressure[1] for the fuel feed system is controlled by the structural design criteria. The design pressure for the Thrust Chamber Injector End Pressure is 1344 psia static. The nominal chamber pressure is 1304 psia static and the minimum pressure is 965 psia static. Application of the structural design factors to determine proof and burst pressure shall be in accordance with paragraph 3.3 Design and Construction.

b. CHECKOUT PRESSURE - The maximum checkout pressure[1] (gaseous nitrogen) to be used for leak testing purposes is 32 psig.

c. SAFE OPERATING PRESSURE - The safe operating pressure for this system is the maximum checkout pressure specified in paragraph 3.1.1.2.1.3b Checkout Pressure. The thrust system shall comply with the requirements of paragraph 3.1.2.7.1.2 Safe Operating Pressure.

3.1.1.2.1.4 FLUID TEMPERATURE - The fluid temperature requirements are tabulated in Tables B-1 and C-1.

3.1.1.2.1.5 ALLOWABLE LEAKAGE - The thrust system shall be designed for zero external leakage.

3.1.1.2.1.6 DRAINAGE - The thrust system shall be capable of being completely drained of residual fluids in accordance with paragraph 3.1.2.7.2.15 Propellant Draining.

3.1.1.2.1.7 STEADY STATE OPERATION - The thrust system shall be designed to have the following characteristics.

a. DYNAMIC STABILITY - The thrust system shall be designed to be dynamically stable[1] as defined by paragraph 3.1.2.7.2.5 Dynamic Stability throughout the designed operating range as defined by paragraph 3.1.1.1.2.2c Thrust Adjustment Capability.

b. VIBRATION LOADS - The thrust system shall be designed to limit self induced vibration loads such that vibration levels do not exceed 35 g's rms, within the frequency range of 10 to 5000 Hz, measured along the thrust chamber longitudinal axis by accelerometers mounted on the oxidizer dome and reduced to a time averaged value[1].

3.1.1.2.2 FUEL FEED SYSTEM - The function of the Fuel Feed System shall be to impart energy to, and transfer vehicle or stage/facility supplied RP-1 to the thrust system combustion zone. The primary components of the fuel feed system shall include: pump inlet ducting, pump, pump discharge ducting, control valving, flow control orificing, thrust chamber distribution manifold, and thrust chamber injector. The functional performance of the fuel feed system shall include the following characteristics. The detailed fuel feed system quantitative characteristics are tabulated in Tables B-1 and D-1.

TABLE D-1

FUEL FEED SYSTEM CHARACTERISTICS

| COMPONENT | PARAMETER NAME | SYMBOL | UNITS | RATING NOMINAL | MINIMUM | MAXIMUM |
|---|---|---|---|---|---|---|
| Pump | Speed Ratio[11] | N/Nc | - | 1.0 | 0.975 | 1.025 |
| | Efficiency Ratio[12] | $\eta$rf | - | 1.0 | 0.975 | 1.025 |
| Ducts | Fluid Resistance | Zlf | [13] | 0.00280 | 0.00245 | 0.00315 |
| Valves | Fluid Resistance (Open) | Zvf | [13] | 0.01200 | 0.01044 | 0.01356 |
| Orifices | Fluid Resistance | Zrf | [13] | 0.00860 | 0.0 | 0.02500 |
| Thrust Chamber Body | Fluid Resistance | Zjf | [13] | 0.00475 | 0.00400 | 0.00550 |
| Injector | Fluid Resistance | Zkf | [13] | 0.00200 | 0.00175 | 0.00225 |

[11]The actual pump speed divided by the chart speed (per Figure TBD) required to produce the actual head and flow.
[12]The effective efficiency of a particular pump at a specified Q/N divided by the chart efficiency (per Figure TBD) at that same Q/N.
[13]$sec^2/in^2\text{-}ft^3$

3.1.1.2.2.1 FLUIDS HANDLED - The fuel feed system shall accept vehicle/facility supplied RP-1 for

starting and operation. The system shall also be compatible with RP-1, trichloroethylene, water, and gaseous nitrogen.

3.1.1.2.2.2 FLUID FLOWRATES - The nominal PP-1 flowrate into the fuel feed system from the vehicle/facility (Tables B-1 and D-1) shall be approximately 2100 lb/sec. The fuel feed system shall transfer approximately 1900 lb/sec to the thrust chamber combustion zone, approximately 165 lb/sec to the turbine drive and exhaust system, and approximately 35 lb/sec recirculation flow shall be available for the operational control and the vehicle service system.

3.1.1.2.2.3 FLUID PRESSURES - The fuel feed system shall be capable of accepting vehicle/facility supplied RP-1 and shall be designed for the following pressure criteria.

a. STRUCTURAL DESIGN CRITERIA - The design pressure[1] for the fuel feed system is controlled by the structural design criteria. The design pressure for each component is listed under the column headed maximum in Table D-2. Application of the structural design factors to determine proof and burst pressure shall be in accordance with paragraph 3.3 Design and Construction.

TABLE D-2

| COMPONENT NAME | PPESSURE PSIA STATIC NOMINAL | MINIMUM | MAXIMUM |
|---|---|---|---|
| Turbopump Inlet | 41.4 | 21.1 | 252.9 |
| Turbopump Discharge | 2129 | 1466 | 2362 |
| Ducting | 2129 | 1466 | 2362 |
| Valve | 2080 | 1436 | 2311 |
| Orifice | 1869 | 1360 | 2181 |
| Thrust Chamber Inlet Manifold & Jacket | 1716 | 1222 | 1901 |
| Injector Inlet Manifold | 1440 | 1046 | 1600 |

b. CHECKOUT PRESSURE - The maximum checkout pressure[1] (gaseous nitrogen) to be used for leak testing purposes is 85 psig for all portions of the fuel feed system upstream of the closed main fuel valve. The maximum checkout pressure

(gaseous nitrogen) to be used for leak testing purposes downstream of the main fuel valve is 32 psig.

c. SAFE OPERATING PRESSURE - The safe operating pressures for this system are the maximum checkout pressures[1] specified in paragraph 3.1.1.2.2.3b Checkout Pressure. The fuel feed system shall comply with the requirements of paragraph 3.1.2.7.1.2 Safe Operating Pressure.

3.1.1.2.2.4 FLUID TEMPERATURES - The fuel feed system shall be capable of accepting vehicle/facility supplied RP-1 at temperatures in accordance with Table B-1.

3.1.1.2.2.5 POWER INPUTS - The fuel feed system shall receive the following power inputs.

a) MECHANICAL - Mechanical power shall be supplied by the Operational Control System for actuation of the control valving. This power input shall meet the sequence requirements of paragraph 3.1.1.2.5 Operational Control System.

b) MECHANICAL - The pump shall be supplied with shaft power from the turbine drive and exhaust system in accordance with the requirements of Table B-1.

3.1.1.2.2.6 ALLOWABLE LEAKAGE - The fuel feed system shall be designed for zero external leakage. Internal leakage shall be minimized and disposed of within the fuel feed system. Propellant valves shall meet the requirements of paragraph 3.1.2.7.2.14 Propellant Valve Leakage.

3.1.1.2.2.7 DRAINAGE - The fuel feed system shall be capable of being completely drained of residual fluids in accordance with paragraphs 3.1.2.2.2 Service and Access and 3.1.2.7.2.15 Propellant Draining.

3.1.1.2.2.8 GAS ENTRAPMENT - The fuel feed system shall be designed to minimize gas entrapment upstream of the control valves during and after acceptance of fuel from the vehicle/facility into the system prior to engine starting. The system shall also be designed to minimize gas entrainment throughout the system during engine starting.

3.1.1.2.2.9 FLOW CONTROL ORIFICING - The fuel feed system shall be designed to have orificing capability for flow control. The resistance range of these variable orifices shall meet the requirements of Table D-1. The orifices and locations are as follows:

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1. Number 1 Fuel Feed orifice located at the Number 1 Thrust Chamber fuel inlet.

2. Number 2 Fuel Feed orifice located at the Number 2 Thrust Chamber fuel inlet.

3. Fuel Feed System Bleed Orifice located at the [illegible] must also bleed the GG fuel system.

3.1.1.2.3 OXIDIZER FEED SYSTEM - The function of the oxidizer feed system shall be to impart energy to, and transfer vehicle/facility supplied oxidizer to the thrust system combustion zone. The primary components of the oxidizer feed system shall include: pump, pump discharge ducting, control valving, flow control orificing, thrust chamber distribution manifold, and thrust chamber injector. The functional performance of the oxidizer feed system shall include the following characteristics. The detailed quantitative characteristics are tabulated in Tables B-1 and E-1.

TABLE F-1

OXIDIZER FEED SYSTEM CHARACTERISTICS

| COMPONENT | PARAMETER NAME | SYMBOL | UNITS | RATINGS NOMINAL | MINIMUM | MAXIMUM |
|---|---|---|---|---|---|---|
| Pump | Speed Ratio[11] | N/Nc | - | 1.00 | 0.975 | 1.025 |
| | Efficiency Ratio[12] | $\eta$ro | - | 1.00 | 0.975 | 1.025 |
| Ducts | Fluid Resistance | Zlo | [13] | 0.00020 | 0.00018 | 0.00022 |
| Valves | Fluid Resistance (open) | Zvo | [13] | 0.00155 | 0.00135 | 0.00175 |
| Orifices | Fluid Resistance | Zro | [13] | 0.0 | 0.0 | 0.00100 |
| Dome | Fluid Resistance | Zmo | [13] | 0.00030 | 0.00026 | 0.00034 |
| Injector | Fluid Resistance | Zko | [13] | 0.00118 | 0.00100 | 0.00135 |

[11]The actual pump speed divided by the chart speed (per Figure TBD) required to produce the actual head and flow.
[12]The effective efficiency of a particular pump at a specified Q/N divided by the chart efficiency (per Figure TBD) at that same Q/N.
[13]$sec^2/in^2\text{-}ft^3$

3.1.1.2.3.1 FLUIDS HANDLED - The oxidizer feed system shall accept vehicle/facility supplied liquid oxygen for starting and

operation. The system shall also be compatible with trichloroethylene and gaseous nitrogen.

3.1.1.2.3.2 FLUID FLOWRATES - The nominal liquid oxygen flowrate into the oxidizer feed system from the vehicle/facility (Tables B-1 and E-1) shall be approximately 4675 lb/sec. The oxidizer feed system shall transfer approximately 4600 lb/sec to the thrust system, approximately 65 lb/sec to the turbine drive and exhaust system, and approximately 10 lb/sec shall be available for the vehicle service system.

3.1.1.2.3.3 FLUID PRESSURES - The oxidizer feed system shall be capable of accepting vehicle/facility supplied liquid oxygen and shall be designed for the following pressure criteria.

a. STRUCTURAL DESIGN CRITERIA - The design pressure[1] for the oxidizer feed system is controlled by the structural design criteria. The design pressure for each component is listed under the column headed maximum in Table E-2. Application of the structural design factors to determine proof and burst pressure shall be in accordance with paragraph 3.3 Design and Construction.

TABLE E-2

| COMPONENT NAME | PRESSURE PSIA STATIC NOMINAL | MINIMUM | MAXIMUM |
|---|---|---|---|
| Turbopump Inlet | 51.1 | 45.8 | 376.9 |
| Turbopump Discharge | 1803 | 1219 | 2100 |
| Ducting | 1803 | 1219 | 2100 |
| Valve | 1789 | 1212 | 2100 |
| Orifice | 1675 | 1151 | 1870 |
| Thrust Chamber Inlet | 1675 | 1151 | 1870 |
| Thrust Chamber Injector | 1651 | 1145 | 1838 |

b. Checkout Pressure - The maximum checkout pressure[1] (gaseous nitrogen) to be used for leak check purposes is 85 psig for all portions of the oxidizer feed system upstream of the closed main oxidizer valve. The maximum checkout to be used for leak check purposes downstream of the main oxidizer valve is 32 psig.

c. Safe Operating Pressure - The safe operating pressures for this system are the maximum checkout pressures[1] specified in paragraph 3.1.1.2.3.3.b Checkout Pressure. The oxidizer feed system shall comply with the requirements of paragraph 3.1.2.7.1.2 Safe Operating Pressure.

3.1.1.2.3.4 FLUID TEMPERATURES - The oxidizer feed system shall be capable of accepting vehicle/facility supplied liquid oxygen at temperatures in accordance with Table B-1.

3.1.1.2.3.5 POWER INPUTS - The oxidizer feed system shall receive the following power inputs.

a) MECHANICAL - Mechanical power shall be supplied by the Operational Control System for actuation of the control valving. This power input shall meet the sequence requirements of paragraph 3.1.1.2.5 Operational Control System.

b) MECHANICAL - The pump shall be supplied with shaft power from the turbine drive and exhaust system in accordance with the requirements of Table B-1.

3.1.1.2.3.6 ALLOWABLE LEAKAGE - The oxidizer feed system shall be designed for zero external leakage. Internal leakage shall be minimized and disposed of within the oxidizer feed system. Propellant valves shall meet the requirements of paragraph 3.1.2.7.2.14 Propellant Valve Leakage.

3.1.1.2.3.7 DRAINAGE - Drainage of the oxidizer system shall be accomplished by normal boiloff of the liquid oxygen in accordance with paragraphs 3.1.2.2.2 Service and Access and 3.1.2.7.2.15 Propellant Drainage.

3.1.1.2.3.8 FLOW CONTROL ORIFICING - The oxidizer feed system shall be designed to have the capability for flow control. The resistance range for these variable orifices shall meet the requirements of Table E-1. The orifices and locations are as follows:

1. Number 1 oxidizer feed orifice located at the Number 1 Oxidizer dome inlet.

2. Number 2 oxidizer feed orifice located at the Number 2 Oxidizer dome inlet.

3.1.1.2.4 TURBINE DRIVE AND EXHAUST SYSTEM - The function of the turbine drive and exhaust system shall be to develop shaft power from the combustion of fuel and oxidizer feed system supplied propellants and to exhaust the used products of combustion. The primary components of the turbine drive and exhaust system shall include: oxidizer feed ducting, fuel feed ducting, sequence control valving, thrust control valving, gas generator, turbine, and exhaust ducting. The functional performance of the turbine drive and exhaust system shall include the following characteristics. The detailed quantitative characteristics are tabulated in Tables B-1 and F-1.

TABLE F-1

TURBINE DRIVE AND EXHAUST SYSTEM
GAS GENERATOR FUEL FEED CHARACTERISTICS

| COMPONENT | PARAMETER NAME | SYMBOL | UNITS | RATINGS NOMINAL | MINIMUM | MAXIMUM |
|---|---|---|---|---|---|---|
| Scoop | Fluid Resistance | Zgbf | [11] | 0.150 | 0.130 | 0.170 |
| Orifice | Fluid Resistance | Zgrf | [11] | 0.380 | 0.0 | 1.450 |
| Line | Fluid Resistance | Zglf | [11] | 0.370 | 0.320 | 0.420 |
| Valve | Fluid Resistance | Zgvf | [11] | 0.236[12] | 0.200[12] | 0.270[12] |
| Injector | Fluid Resistance | Zgkf | [11] | 0.870 | 0.760 | 0.980 |

[11] $sec^2/in^2\text{-}ft^3$
[12] Fully open fluid resistance, for transient resistance see Figure F-1

TABLE F-1
(Continued)

TURBINE DRIVE AND EXHAUST SYSTEM
GAS GENERATOR OXIDIZER FEED CHARACTERISTICS

| COMPONENT | PARAMETER NAME | SYMBOL | UNITS | RATINGS NOMINAL | MINIMUM | MAXIMUM |
|---|---|---|---|---|---|---|
| Scoop | Fluid Resistance | Zgbo | [11] | 0.350 | 0.304 | 0.396 |
| Throttle Valve | Fluid Resistance (Full Open) | Zgtvo | [11] | 1.240 | 1.100 | 1.440 |
| | Fluid Resistance Increase | $\Delta$Zgtvo | [11] | 10.27<br>6.217[12] | 0.0<br>0.0[12] | 11.97<br>8.065[12] |
| Orifice | Fluid Resistance | Zgro | [11] | 1.810 | 0.0 | 10.0 |
| Line | Fluid Resistance | Zglo | [11] | 1.270 | 1.100 | 1.440 |
| Valve | Fluid Resistance | Zgvo | [11] | 0.845[13] | 0.735[13] | 0.955[13] |
| Injector | Fluid Resistance | Zhko | [11] | 6.000 | 5.220 | 6.780 |

[11] $sec^2/in^2\text{-}ft^3$
[12] for use on "LOX Only Throttling" engines
[13] Fully open fluid resistance, for transient resistance see Figure F-2

TABLE F-1
(Continued)

TURBINE DRIVE AND EXHAUST SYSTEM
HOT GAS SYSTEM CHARACTERISTICS

| COMPONENT | PARAMETER NAME | SYMBOL | UNITS | RATINGS NOMINAL | MINIMUM | MAXIMUM |
|---|---|---|---|---|---|---|
| GG Combustor | Isothermal Fluid Resistance | Kg | [14] | 0.030 | 0.027 | 0.033 |
| Turbine | Effective Nozzle Area | Ati | $in^2$ | 20.84 | 18.40 | 23.28 |
| | Torque Parameter Ratio[11] | PARt | - | 1.00 | 0.97 | 1.03 |
| Flow Straightener | Isothermal Fluid Resistance | Kted | [14] | 0.000058 | 0.000052 | 0.000064 |
| Heat Exchanger | Isothermal Fluid Resistance | Ktex | [14] | 0.000410 | 0.000370 | 0.000450 |
| Exhaust Manifold | Isothermal Fluid Resistance | Ktem | [14] | 0.000228 | 0.000200 | 0.000255 |
| Nozzle Extension | Isothermal Fluid Resistance[12] | Ktee | [14] | 0.000024 | 0.000020 | 0.000028 |
| | Effective Nozzle Area[13] | Aten | $in^2$ | 460.0 | 445.0 | 475.0 |

[11]Effective torque parameter at actual speed parameter and pressure ratio divided by chart torque parameter (Figure TBD) at actual speed parameter and pressure ratio.
[12]From entrance to effective nozzle area.
[13]Effective area of a sonic nozzle exiting into main chamber nozzle at an expansion ratio of 13:1.
[14]$sec^2$-lb/$in^4$-lb mole-F

3.1.1.2.4.1 FLUIDS HANDLED - The turbine drive and exhaust system shall accept liquid oxygen and RP-1/RJ-1 from the oxidizer and fuel feed systems respectively for operation. The system shall also be compatible with trichloroethylene and gaseous nitrogen.

3.1.1.2.4.2 FLUID FLOWRATES - The nominal flowrates through the turbine drive and exhaust system shall be in accordance with Tables B-1 and F-1.

3.1.1.2.4.3 FLUID PRESSURES - The turbine drive and exhaust system shall be designed for the following pressure criteria.

a. STRUCTURAL DESIGN CRITERIA - The design pressure for the gas generator (GG) fuel feed system is controlled by the structural design criteria. The design pressure for each component in the GG fuel feed system is listed under the column headed maximum in Table F-2. Application of the structural design factors to determine proof and burst pressure shall be in accordance with paragraph 3.3 Design and Construction.

TABLE F-2
GG FUEL FEED SYSTEM

| COMPONENT NAME | PRESSURE PSIA STATIC NOMINAL | MINIMUM | MAXIMUM |
|---|---|---|---|
| Scoop Inlet | 2118 | 1302 | 3000 |
| Orifice Inlet | 2066 | 889 | 3000 |
| Ducting Inlet | 1715 | 752 | 3000 |
| Shutoff Valve Inlet | 1589 | 719 | 3000 |
| GG Injector Inlet | 1463 | 693 | 1755 |

The design pressure for the GG oxidizer feed system is controlled by the structural design criteria. The design pressure for each component in the GG oxidizer feed system is listed under the column headed maximum in Table F-3. Application of the structural design factors to determine proof and burst pressure shall be in accordance with paragraph 3.3 Design and Construction.

TABLE F-3
GG OXIDIZER FEED SYSTEM

| COMPONENT NAME | PRESSURE PSIA STATIC NOMINAL | MINIMUM | MAXIMUM |
|---|---|---|---|
| Scoop Inlet | 1843 | 1155 | 3000 |
| Throttle Valve Inlet | 1828[11] | 1243 | 3000 |
| Orifice Inlet | 1782[11] | 891 | 3000 |
| Orifice Inlet | 1828 | 891 | 3000 |
| Ducting Inlet | 1675 | 742 | 3000 |
| Shutoff Valve Inlet | 1598 | 719 | 3000 |
| GG Injector Inlet | 1546 | 710 | 1849 |

[11]When throttle valve used.

The design pressure for the hot gas portion of the turbine drive and exhaust system is controlled by the structural design criteria. The design pressure for each component in the GG Hot Gas System is listed under the column headed maximum in Table F-4. Application of the structural design factors to determine proof and burst pressure shall be in accordance with paragraph 3.3 Design and Construction.

TABLE F-4
GG HOT GAS SYSTEM

| COMPONENT NAME | PRESSURE PSIA STATIC NOMINAL | MINIMUM | MAXIMUM |
|---|---|---|---|
| GG Chamber Injector End | 1131 | 598 | 1378 |
| Turbine Inlet | 1051 | 542 | 1303 |
| Flow Straightener Inlet | 71.7 | 38.2 | 78.6 |
| Heat Exchanger Inlet | 70.8 | 37.3 | 77.6 |
| Exhaust Manifold Inlet | 59.6 | 31.5 | 65.3 |
| Nozzle Extension Inlet | 34.3 | 18.1 | 37.6 |

b. CHECKOUT PRESSURE - The maximum checkout pressure[1] (gaseous nitrogen) to be used for leak testing purposes is 85 psig for all portions of the GG fuel and oxidizer feed systems upstream of the closed shutoff valve. The maximum checkout pressure (gaseous nitrogen) to be used for leak testing purposes downstream of the closed shutoff valve is 12 psig.

c. SAFE OPERATING PRESSURE _ The safe operating pressure for this system are the maximum checkout pressures specified in paragraph 3.1.1.2.4.3b Checkout Pressure. The turbine drive and exhaust system shall comply with the requirements of paragraph 3.1.2.7.1.2 Safe Operating Pressure.

3.1.1.2.4.4 FLUID TEMPERATURE - The turbine drive and exhaust system shall be capable of handling RP-1 and liquid oxygen from the fuel and oxidizer feed systems in accordance with the requirements of Table B-1, 3.1.1.2.2 Fuel Feed System and 3.1.1.2.3 Oxidizer Feed System. The hot gas portions of the system shall also meet the requirements of Table B-1.

3.1.1.2.4.4.1 RATED TURBINE INLET TEMPERATURE - The rated turbine inlet temperature shall be 1500F, when engine operation is corrected to the conditions of paragraph 3.1.1.1.2.1 Standard Conditions.

3.1.1.2.4.5 POWER INPUTS - The turbine drive and exhaust system shall receive the following power inputs:

a) MECHANICAL - Mechanical power shall be supplied by the operational control system for actuation of the sequence control valving. This power input shall meet the sequence requirements of paragraph 3.1.1.2.5 Operational Control System.

b) MECHANICAL - Mechanical power shall be supplied by the thrust control system for operation of the thrust control valving. This power input shall meet the requirements of the thrust control system and the fluid resistance requirements of Table F-1.

3.1.1.2.4.6 POWER OUTPUTS - The turbine drive and exhaust system shall generate the following power outputs:

a) MECHANICAL - The turbine shall develop a shaft power output which meets the input power requirements of the oxidizer and fuel feed systems, tabulated in Table B-1.

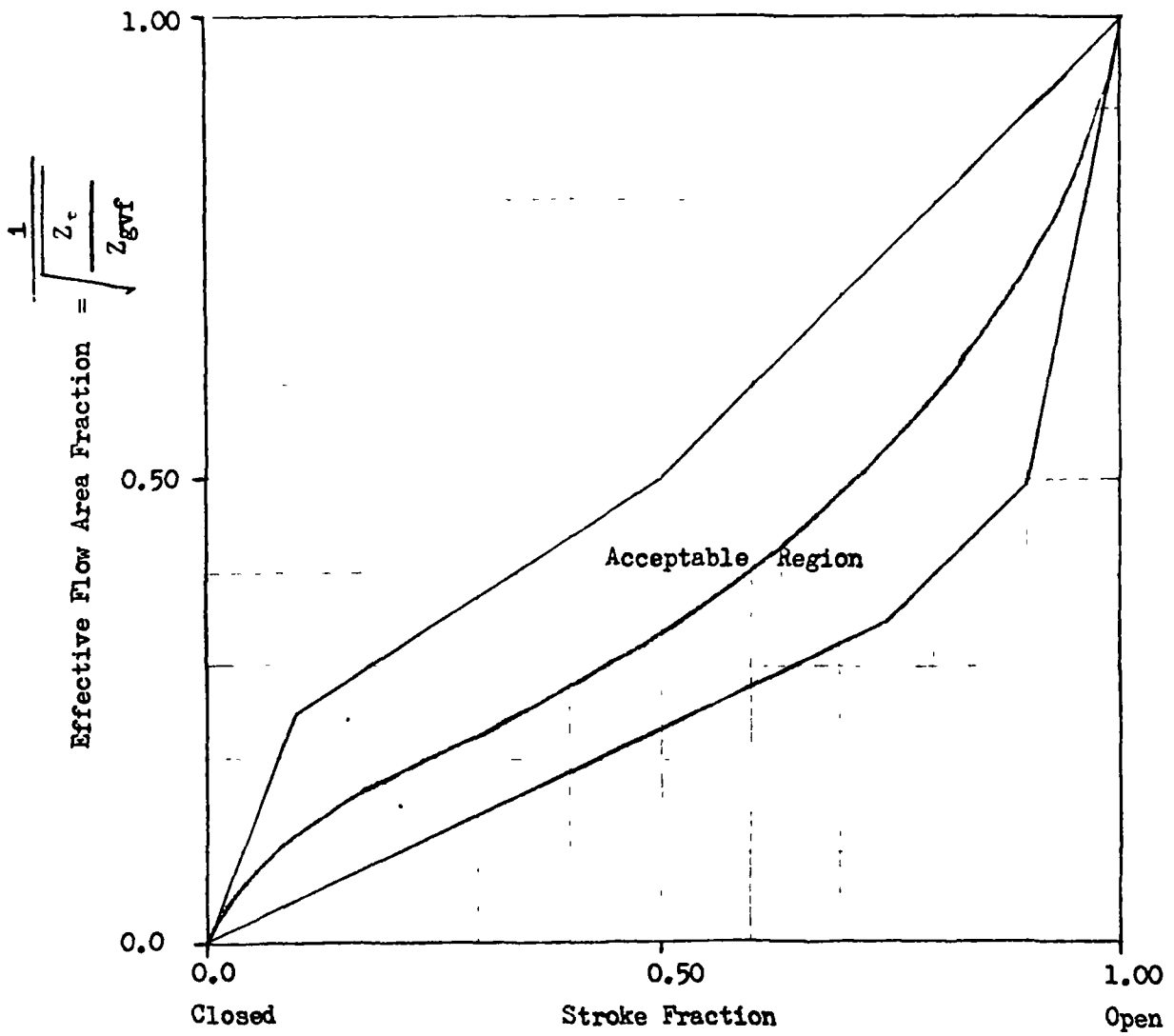
3.1.1.2.4.7 ALLOWABLE LEAKAGE - The turbine drive and exhaust system shall be designed for zero external leakage. Internal leakage shall be minimized and disposed of within the turbine drive and exhaust system. Propellant valves shall meet the requirements of paragraph 3.1.2.7.2.14 Propellant Valve Leakage.

3.1.1.2.4.8 DRAINAGE - The turbine drive and exhaust system shall be capable of being completely drained of residual fluids in accordance with paragraphs 3.1.2.2.2 Service and Access and 3.1.2.7.2.15 Propellant Draining.

3.1.1.2.4.9 FLOW CONTROL ORIFICING - The turbine drive and exhaust system shall be designed to have flow control orificing. The resistance of these variable orifices shall meet the requirements of Table F-1. The locations of these orifices shall be as follows.

1. Gas generator fuel feed system orifice located at the interface between the fuel feed system and the gas generator fuel feed line. Provision shall also be provided for an orifice at the interface between the feed line and the shutoff valve.

2. Gas generator oxidizer feed system orifice located at the interface between the oxidizer throttle valve and the gas generator oxidizer feed system. Provision shall also be provided for an orifice at the interface between the oxidizer feed line and the shutoff valve.



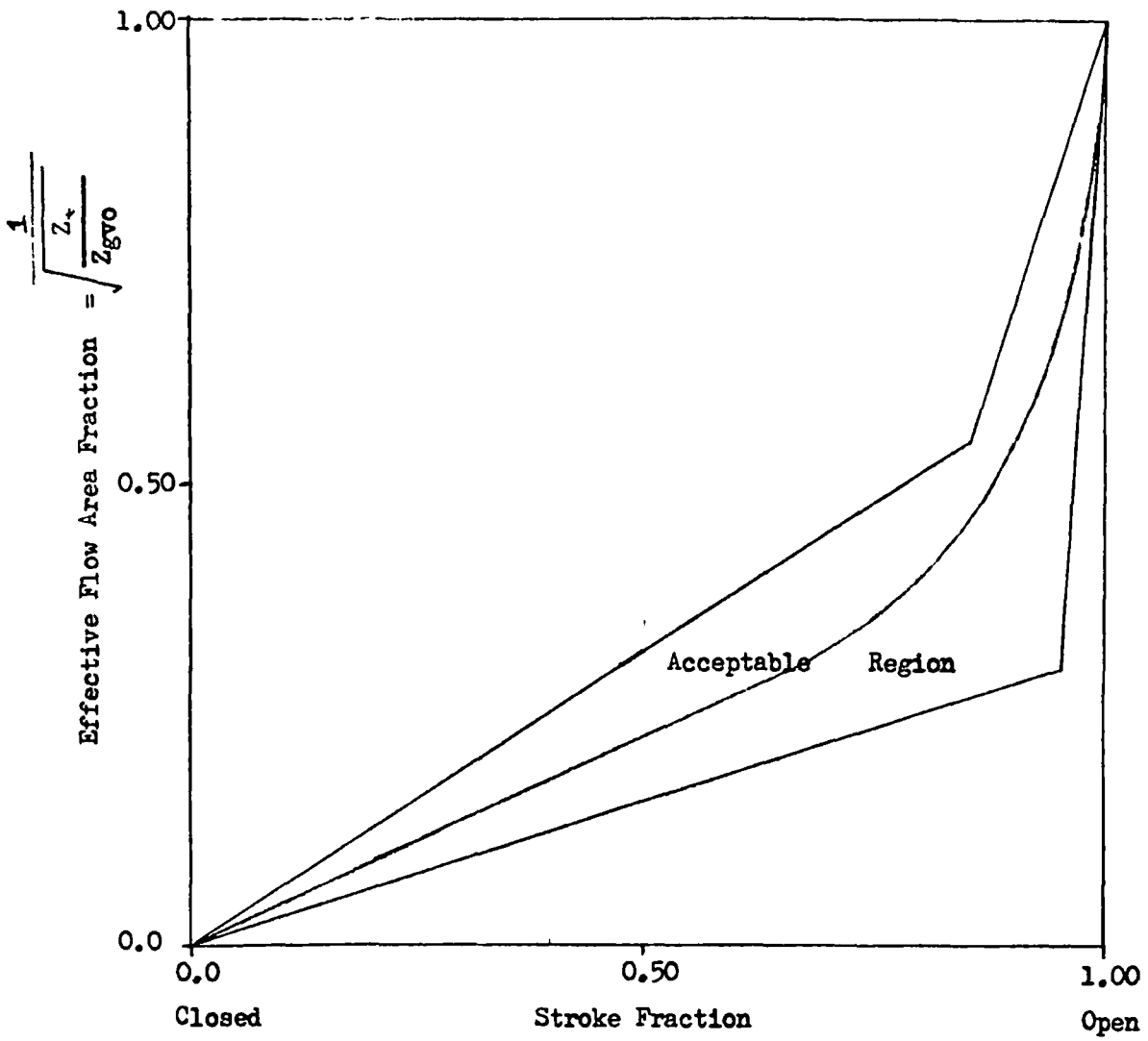

NOTE: $Z_t = (Z_{gvf}) / (\text{Effective Flow Area Fraction})^2$

$$Z_{gvf} = \frac{(\Delta P \text{ full open})\ (\text{fluid density})}{(\text{flowrate})^2}$$

$$\Delta P = \frac{(Z)\ (\text{flowrate})^2}{\rho}$$

GAS GENERATOR FUEL SHUTOFF VALVE TRANSIENT CHARACTERISTICS

Figure F-1




NOTE: $Z_t = (Z_{gvo}) / (\text{effective flow area fraction})^2$

$$Z_{gvo} = \frac{(\Delta P \text{ full open})\ (\text{fluid density})}{(\text{flowrate})^2}$$

$$\Delta P = \frac{(Z_t)\ (\text{flowrate})^2}{\rho}$$

GAS GENERATOR LOX SHUTOFF VALVE TRANSIENT CHARACTERISTIC

Figure F-2

3.1.1.2.5 OPERATIONAL CONTROL SYSTEM - The function of the operational control system shall be to provide the sequencing and safety interlocks for satisfactory engine starting and stopping. In addition, the system shall provide porting for supplying hydraulic fluid to and receiving hydraulic fluid from the gimbal actuators. A description of the operation and engine sequence is provided in paragraph 6.1 Supplemental Information. A schematic is provided in Figure 10-1. The operational control system consists of propellant valve actuators, control elements required for sequencing, elements required for functional indications and interconnecting lines. Sequence control elements of the operational control system are as follows.

a. ENGINE CONTROL UNIT - The Engine Control Unit contains:

1. Two start solenoids, each with its slave pilot valve

2. Two stop solenoids, each with its slave pilot valve

3. A hydraulic control valve with redundant actuation pistons for open and closed position

4. A redundant gas generator closing control valve with redundant actuation pistons

b. ENGINE ARMING UNIT - The Engine Arming Unit contains:

1. Igniter fuel control valve

2. Igniter fuel shutoff valve

3. Hypergol manifold

4. Hydraulic return flow control valve

5. Engine arming valve

6. Hypergol cartridge follower

7. Pressure Switch Checkout Valve

8. Engine Monitor Valve

c. IGNITION CONTROL UNIT - The Ignition Control Unit contains:

1. Thrust chamber ignition monitor valve

2. Main fuel valve control valve

The Sequence Instrumentation Unit contains function indication elements. These elements receive hydraulic signals from the monitored functions and provide indication of functional operation with the output of an electrical transducer. A description of the operation of the Sequence Instrumentation Unit is provided in paragraph 6.1, Supplemental Information. A schematic is provided in Figure 10-1. The sequence instrumentation unit contains the following:

a. Primary sequence valves

b. Auxiliary sequence valves

c. Electrical transducers

d. Sequence control valves

In addition the operational control system contains three pressure switches, the No. 1 hydraulic supply check valves, filters and retainer assemblies and the No. 2 hydraulic supply check valve, filter and retainer assembly. These filter assemblies shall contain a pressure drop indicator and a "Quick Disconnect" for draining and purging of the Operational Control System.

3.1.1.2.5.1 FLUIDS HANDLED - The operational control system and individual components shall be capable of operation with RJ-1 or RP-1 fuels.

3.1.1.2.5.2 FLUID FLOWRATES - The operational control system shall be designed to be in a ready condition with a fluid flowrate less than 40 gpm. This flowrate consists of 15 gpm maximum to the gimbal hydraulic supply interfaces, 5 gpm maximum to the turbopump warmant system; 20 gpm maximum to the operational control system elements (valve actuator bleed flows, control elements bleed flows, gas generator valve warmant and any other valve actuator bleed and/or warmant required). During starting transient operation the fluid flowrate from the ground system shall be less than 200 gpm and during engine operation the flowrate shall be less than 350 gpm. Detailed characteristics are presented in Figure G-1.

3.1.1.2.5.3 FLUID PRESSURES - The operational control system supply and return system lines and all fluid passages in

components, including signal passages specified in subsequent paragraphs, shall be designed in accordance with the following pressure criteria.

a. FUNCTIONAL OPERATING RANGE - 1200 to 2400 psig
The system and components must function (i.e. actuate, deactuate) satisfactorily when provided a supply pressure from the ground or engine within this range. Ground and engine supply requirements are specified in subsequent paragraphs.

b. MAXIMUM TRANSIENT PRESSURE - 4000 psig (surges are included in this value)
The system and components would not be expected to function at this pressure and personnel would not be present when operating at this pressure. This value results from the maximum engine supply pressure combined with expected gimbal system surges.

c. SAFE OPERATING PRESSURE - 3000 psig
The system would not be expected to function at this pressure, however, personnel, without additional protection, could be present when the system is pressurized to this value.

d. RETURN SYSTEM PRESSURE - Maximum Transient and Safe Operating Return System pressure for the portions described in this paragraph only are as follows.

1. GROUND RETURN SYSTEM - The Lines components and passages from the engine interface to and including the Ground Return portions of the Engine Arming unit shall be designed for a Maximum Transient Pressure of 700 psia and a safe operating pressure of 500 psia.

2. ENGINE RETURN SYSTEM - The Lines, components and passages from the turbopump inlet flange to and including the engine return portions of the engine arming units shall be designed for a Maximum Transient Pressure of 700 psia and a safe operating pressure of 500 psia.

Structural design safety factors for proof and burst pressure determination shall be in accordance with paragraph 3.3 Design and Construction. Safe Operating Pressure safety factors policy shall be determined in accordance with paragraph 3.1.2.7.1.2 Safe Operating Pressure.

All operational control system subsystems, lines and components, including the actuator portions of the Main Propellant Valves and Gas Generator Valve, shall be designed to be capable of an operational mode proof test as follows:

a. Proof pressure applied to supply and return ports simultaneously.

b. Proof pressure applied to system supply port with all components in the closed position and ground return system pressure in accordance with paragraph 3.1.1.2.5.6 POWER OUTPUTS.

c. Proof pressure applied to system supply port with all components in the open position and the ground return system pressure in accordance with paragraph 3.1.1.2.5.6 POWER OUTPUTS.

d. The redundant close supply system for the gas generator valve shall be proof pressurized with the stop solenoids energized.

3.1.1.2.5.4 FLUID TEMPERATURES - The operational control system shall be designed to operate satisfactorily with fluid temperatures in the range of 35F to 150F.

3.1.1.2.5.5 POWER INPUTS - The operational control system shall receive the following inputs:

a. HYDRAULIC - The operational control system shall receive hydraulic power from a ground hydraulic system for engine starting and checkouts. The range of pressures available shall be 1200 psig minimum, 2200 psig maximum and with a nominal pressure of 1500 ±100 psig. Detailed quantitative characteristics are presented in Figures G-2 and G-3.

b. HYDRAULIC - The operational control system shall receive hydraulic power from the fuel feed system during engine operation. The range of pressures available shall be 1300 psig minimum, 2300 psig maximum. This available pressure varies with engine operating level. The available flowrate range shall be 105 gpm minimum and 380 gpm maximum. This flowrate is required for control element bleeds (valves, actuators, warmants), gimbal supply, and the igniter fuel supply. The detailed quantitative characteristics are presented in Figures G-1, G-2, G-4 and G-5.

c. HYDRAULIC - The operational control system shall receive hydraulic fluid from the gimbal actuator return system. The flowrate range for this input shall be zero to 85 gpm at each interface. The resistance of this return system shall be such that the maximum pressure at the gimbal actuator interface is 200 psig.

d. HYDRAULIC - The operational control system (Ignition Monitor Valve portion of the Ignition Control Unit) shall receive a fluid signal indicating satisfactory thrust chamber ignition. The signal level indicating satisfactory thrust chamber ignition is 15 to 35 psig (25 psig nominal). The ignition monitor valve shall be designed to operate at this level. The maximum pressure level that this signal attains is 1872 psig. The ignition monitor valve control port shall be designed for 4000 psig in accordance with paragraph 3.1.1.2.5.3b Fluid Pressures.

e. HYDRAULIC - The operational control system (main fuel valve control valve portion of the Ignition Control Unit) shall receive a fluid signal indicating satisfactory gas generator ignition/turbopump operation. The signal level indicating satisfactory operation is 150 to 400 psig (250 psig nominal). The main fuel valve control valve shall be designed to operate at this level. The maximum pressure level that this signal attains is 2285 psig and the main fuel valve control valve control port shall be designed for 4000 psig in accordance with paragraph 3.1.1.2.5.3b Fluid Pressures.

f. HYDRAULIC - The operational control system (Engine Monitor Unit) shall receive a fluid signal, generated internally to the operational control system, indicating satisfactory engine operation/thrust level has been attained. The pressure range for this signal is 44 psig to 2285 psig. The maximum pressure level that this signal attains is 2285 psig and the Engine Monitor Unit port shall be designed for 4000 psig, in accordance with paragraph 3.1.1.2.5.3b Fluid Pressures.

g. MECHANICAL - The operational control system shall receive mechanical power to the engine arming valve when the hypergol cartridge is installed. This mechanical signal shall provide a minimum force of TBD pounds, a maximum force

of TBD pounds (nominal force TBD pounds) and a minimum displacement of TBD inches, a maximum displacement of TBD inches (nominal displacement TBD inches). When installed, the hypergol cartridge shall mechanically lock the position of the engine arming valve.

h. ELECTRICAL - The operational control system shall receive redundant electrical signals within the range of 18 to 36 vdc, TBD watts, to initiate the engine start sequence. The duration of these signals shall be more than 0.10 seconds and less than 180 seconds.

i. ELECTRICAL - The operational control system shall receive redundant electrical signals within the range of 18 to 36 vdc, TBD watts, to initiate the engine stop sequence. The duration of these signals shall be more than 0.10 seconds and less than 180 seconds.

j. ELECTRICAL - The operational control system shall receive (TBD) watts of electrical power within the range of 18 to 36 vdc to be used for producing the electrical outputs in accordance with paragraph 3.1.1.2.5.6 Power Outputs.

3.1.1.2.5.6 POWER OUTPUTS - The operational control system shall provide the following outputs.

a. HYDRAULIC - The operational control system shall provide hydraulic power to the gimbal actuator systems. The range of pressure available shall be 1300 psig minimum and 2300 psig maximum. This pressure varies with engine operating level in accordance with Figure G-6. The maximum available flowrate at each of the two interfaces is 85 gpm for a total of 170 gpm.

b. HYDRAULIC - The operational control system shall provide ignition fuel to the ignition system in accordance with Table H-1 for the duration of operation.

c. HYDRAULIC - The operational control system shall provide return hydraulic fluid to the ground return during checkout and standby and to the engine return during engine operation. Detailed quantitative characteristics are presented in Figure G-7 and G-8.

d. MECHANICAL - The operational control system shall provide sequenced mechanical power to the fuel feed system for main valve control in accordance with Table G-1, Figure A-1 and Figure A-2.

e. MECHANICAL - The operational control system shall provide sequenced mechanical power to the oxidizer feed system for main valve control in accordance with Table G-1, Figure A-1 and Figure A-2.

f. MECHANICAL - The operational control system shall provide sequenced mechanical power to the turbine drive and exhaust system for propellant valve control in accordance with Table G-1, Figure A-1 and Figure A-2.

g. MECHANICAL - The operational control system shall provide sequenced mechanical power to the ignition system for valve operation in accordance with Table G-1, Figure A-1 and Figure A-2.

h. ELECTRICAL - The operational control system shall provide an "Engine Ready - Checkout" electrical signal (one pressure switch) indicating that all critical elements that control functions and propellant valves, are in the normally closed standby position, a hypergol cartridge is NOT installed and sufficient hydraulic pressure for checkouts is supplied to the engine. TBD watts of electrical power shall be continuously available when the engine is in the "Engine Ready - Checkout" state.

i. ELECTRICAL - The operational control system shall provide a "Checkout Sequence Complete" electrical signal (three pressure switches) indicating that all valves are in the open position and a hypergol cartridge is NOT installed. TBD watts of electrical power shall be continuously available when the engine is in the "Checkout Sequence Complete" state.

j. ELECTRICAL - The operational control system shall provide an "Engine Armed" electrical signal (two pressure switches) indicating that all critical elements that control functions and propellant valves, are in the normally closed standby position, a hypergol cartridge is installed and sufficient hydraulic pressure for

engine start is supplied to the engine. TBD watts of electrical power shall be continuously available when the engine is in the "Engine Armed" state.

k. ELECTRICAL - The operational control system shall provide an "Engine Thrust OK for Launch Commit" electrical signal (three pressure switches) to be used for "launch commit", indicating completion of the engine start sequence and attainment of a satisfactory thrust level. TBD watts of electrical power shall be continuously available when the engine is in the "Thrust OK for Launch Commit" state.

3.1.2.5.7 ALLOWABLE LEAKAGE - External connections in the operational control system shall be designed to prevent external leakage of operating fluid in any form (wetted surface not allowed). Leakage past internal dynamic seals shall be disposed of internal to the component or system.

3.1.1.2.5.8 OPERATIONAL CONTROL SYSTEM FUNCTIONAL REQUIREMENTS - The operational control system shall be capable of performing the following functions:

a. The system shall be capable of utilizing hydraulic pressure supplied from the engine only or supplied simultaneously from the engine and ground for engine shutdown.

b. The system shall maintain closing pressure on the main fuel valves until verification of thrust chamber ignition.

c. The Engine Arming Unit shall provide for adjustment of the pressure supplied to the "Thrust OK for Launch Commit" indicator (pressure switches). This pressure level shall reflect satisfactory engine operation. The pressure switches (3 total) shall be designed to actuate by 950 psig maximum on increasing pressure and to deactuate by 800 psig minimum on decreasing pressure. The switches shall be non-adjustable.

d. The system shall provide for filtering of both engine and ground supplied hydraulic fluid for both operational and gimbal system operation. The absolute rating of these filters shall be 40 microns absolute with a flow capacity of 200 gpm. After filtration the fluid in the operational control system shall meet the following particulate requirements.

| Particle Size (microns) | Maximum Number Allowable per 100 ml. |
|---|---|
| 10-25 | 5500 |
| 26-50 | 3000 |
| 51-100 | 500 |
| 101-700 & Fibers | 200 |
| >700 | 0 |

Additional filters shall be provided in component ports to prevent the entry of foreign objects which could cause the component to malfunction. The size (ratings are in microns absolute) and location of these filters are:

| Component | Port | Rating |
|---|---|---|
| 1. ECU | Open | 40 |
| | Close | 40 |
| | Red. GG Close | 40 |
| | Solenoid Passage (4)[11] | 25 |
| 2. ICU | Supply IN (MFV) | 165 |
| | MFV Close | 165 |
| | MFV Open | 165 |
| | Position in | 165 |
| | Position out | 165 |
| | MFV Control Close[11] | 165 |
| | Supply IN (GGBV) | 165 |
| | IMV Sense | 165 |
| | Fuel Discharge Sense | 165 |
| | GGBV Open | 165 |
| | Test Orifices[11] | 165 |
| 3. EAU | Hydraulic Return Control Valve Timing Orifice[11] | 165 |
| | Igniter Fuel Supply In Bleed Orifice (GG Sequence Valve) | 165 |
| 4. Pressure Switch Adapter | Bleed Orifices (2) | 165 |

[11] Internal To Component

e. The system shall provide for a constant bleed flow through all control elements whenever hydraulic pressure is applied, sufficient to

remove all air in the system in all engine and stage attitudes in accordance with paragraph 3.1.2.2.2 Service and Access. Propellant valve actuators shall be designed to preclude natural air pockets with the valves in the engine firing position as specified in paragraph 3.1.1.1.3.1 Starting Attitude.

f. The system shall provide temperature control by the use of the operating fluid for critical components with oxidizer propellant in the engine, a steady ambient temperature of -30F and a steady hydraulic fluid temperature of 35F.

g. The Main Propellant valve and Gas Generator valve actuators shall provide a positive closing force that will keep each valve in the closed position during handling and shipping in accordance with paragraph 3.1.2.5 Transportability, with both opening and closing pressures between 0 and 5 psig.

h. The Main Propellant valve and Gas Generator valve actuators shall allow propellant valves to remain in the full open position in the event opening hydraulic pressure is lost after engine "Thrust OK for Launch Commit" indication in accordance with paragraph 3.1.2.7.2.1 Fail Safe Open.

i. The Main Propellant valve and Gas Generator valve actuators shall be designed to the extent possible to maintain a ratio of available force to required force of 20:1 for both valve opening and closing.

j. The main propellant valve and Gas Generator Valve actuators shall provide a positive closing force that will keep the valves in the closed position in accordance with paragraph 3.1.2.7.2.14 Propellant Valve Leakage.

k. The Main Propellant valve actuators shall close the propellant valves upon decay of propellant flow with normal return pressure on both the opening and closing control portions of the actuators. Maximum allowable closing times shall be TBD for the Main Oxidizer valves and TBD for the Main Fuel valves.

l. The system shall be capable of remote (no auxiliary connections) checkout of all control functions required for engine start and shutdown.

m. All hydraulic components that move during engine start and shutdown shall move an equivalent amount during checkout and at approximately the same time and in the same sequence with similar hydraulic fluid flowrates versus time, except igniter fuel flow, with or without the gimbal system installed. Power inputs in accordance with paragraph 3.1.1.2.5.5d, e and f Power Inputs shall be simulated hydraulically.

The following requirements are established for design of components within the Operational Control System to provide gas generator hypergol ignition capability.

a. The gas generator ball valve shall be designed for separate opening of the oxidizer and fuel balls.

b. Opening of the gas generator oxidizer ball shall occur upon receipt of pressure from the sequence valve on the second opening main oxidizer valve.

c. A sequence valve shall be incorporated on the gas generator valve to provide a signal to actuate the igniter fuel control valve when the oxidizer ball has reached the open position.

d. Actuation of the ignition monitor valve (sensing the occurrence of thrust chamber ignition) shall provide pressure for opening of the gas generator valve fuel ball.

e. The gas generator valve shall be designed such that the oxidizer and fuel balls are mechanically coupled during valve closing. The propellant valve balls shall be clocked to allow fuel flow shutoff to occur a minimum of 15 percent of the valve travel after shutoff of LOX flow. Capability of adjusting the fuel lag to 25 percent is a design objective.

f. Installation of the gas generator and thrust chamber hypergol cartridge shall produce an "Engine Armed" signal as part of an existing signal circuit. This feature shall be designed such that:

1. A "Checkout Ready" signal cannot be obtained with the hypergol cartridge installed.

2. An "Engine Armed" signal cannot be obtained unless the hypergol cartridge is installed.

g. The Operational Control System shall be designed for pyrotechnic gas generator ignition as an alternate. Conversion to pyrotechnic igniters shall be accomplished at the engine level and with minimum hardware changes.

h. The functional components of the Operational Control System shall be designed such that no moving parts are exposed to hypergol fluid.

3.1.1.2.5.9 FUNCTIONAL CHECKOUT REQUIREMENTS - The operational control system (Sequence Instrumentation Unit) shall be designed to incorporate the following checkout functional requirements. These checkout requirements shall not constrain launch countdown operations.

a. Indication of individual propellant valve operation and critical control component functions for Start and Shutdown shall be provided during checkout and operation.

b. Indication of the proper functioning of all electrical and hydraulic redundant functions shall be provided. Electrical staggering of the primary and redundant start and stop signals shall be allowed to accomplish this requirement.

c. The Sequence Instrumentation Unit shall be capable of removal and replacement without removing functional hydraulic control components.

d. All functions shall be sensed by a single instrumentation transducer in accordance with paragraph 3.1.1.2.8 Instrumentation System.

e. Failure of the checkout instrumentation shall not prevent proper operational control system operation.

f. Signal types and sources for the sequence instrumentation unit shall be provided as specified in Table G-3. All pressure signal sources, porting, passages, and components shall be designed in accordance with paragraph 3.1.1.2.5.8, Fluid Pressures. Output of a single transducer, in accordance with paragraph

3.1.1.2.8, shall be as described in Drawing 101352 during standby with hydraulic power applied, engine start, engine operation, engine shutdown, and after hydraulic power is re-applied.

3.1.1.2.5.10 REDUNDANCY REQUIREMENTS - The system shall provide redundancy for all critical electrical and hydraulic functions for engine starting and shutdown. These shall include as a minimum:

a. FLECTRICAL - The components providing engine starting functions shall have redundant interfaces, wiring, and control solenoids.

b. ELECTRICAL - The components providing the engine shutdown functions shall have redundant interfaces, wiring and control solenoids.

c. HYDRAULIC - The gas generator valve shall have redundant actuators to close the valve. Redundant sources of closing control pressure shall be provided.

d. ELECTRICAL - The electrical launch commit indication shall have redundant sources, wiring and interfaces.

e. ELECTRICAL - The engine armed indication shall have redundant sources, wiring and interfaces.

f. HYDRAULIC - The hydraulic control valve (Engine Control Unit) shall have redundant actuators on both the open and close functions.

g. Electrical - The Engine Ready-Checkout Mode shall have redundant wiring and interfaces.

3.1.1.2.5.11 ORIFICING - The operational control system shall be designed to allow orificing of control system hydraulic fluid passages. The function and location of these orifice provisions are specified in Table G-2. Type "A" orifices are fixed orifices. Type "B" orifices are variable orifices.

Internal orifices designed to provide bleeding or warmant capability shall be designed such that flow variations on a unit to unit basis is no more than 10 percent of the nominal flowrate.

TABLE G-1

OPERATIONAL CONTROL SYSTEM

| SUBSYSTEM | PARAMETER | UNITS | OPERATING CONDITIONS NOMINAL | MINIMUM | MAXIMUM |
|---|---|---|---|---|---|
| Main Fuel Valve | Travel Time Open | Seconds | 0.500 | 0.400 | 0.700 |
| | Travel Time Close | Seconds | 0.500 | 0.400 | 0.700 |
| | Stroke | Inches | TBD | TBD | TBD |
| | Force Open | Pounds | TBD | TBD | TBD |
| | Force Close | Pounds | TBD | TBD | TBD |
| | Sequence Valve Open | % of Open Travel #1 | (*) | (*)-5 | (*)+5 |
| | | % of Open Travel #2 | (*) | (*)-5 | (*)+5 |
| Main Oxidizer Valve | Travel Time Open | Seconds | 0.500 | 0.400 | 0.600 |
| | Travel Time Close | Seconds | 0.500 | 0.400 | 0.600 |
| | Stroke | Inches | TBD | TBD | TBD |
| | Force Open | Pounds | TBD | TBD | TBD |
| | Force Close | Pounds | TBD | TBD | TBD |
| | Sequence Valve Open | % of Open Travel #1 | 90 | 50 | TBD |
| | | % of Open Travel #2 | 90 | 50 | TBD |
| GG Oxidizer Valve | Travel Time Open | Seconds | 0.300 | 0.120 | 0.500 |
| | Travel Time Close | Seconds | 0.400 | 0.120 | 0.500 |
| GG Fuel Valve | Travel Time Open | Seconds | 0.300 | 0.120 | 0.500 |
| | Travel Time Close | Seconds | 0.300 | 0.120 | 0.500 |
| | Stroke | Inches | TBD | TBD | TBD |
| | Force Open | Pounds | TBD | TBD | TBD |
| | Force Close | Pounds | TBD | TBD | TBD |
| Tc Igniter Fuel Valve | Travel Time Open | Seconds | 0.500 | 0.400 | 0.600 |
| | Travel Time Close | Seconds | 0.500 | 0.400 | 0.600 |

*Nominal value shall be adjustable between 50 and 90 percent of open travel. Maximum and minimum values are the set nominal ±5% of open travel.

TABLE G-2
OPERATIONAL CONTROL SYSTEM ORIFICING

| ORIFICE NAME | ORIFICE LOCATION | ORIFICE TYPE A | ORIFICE TYPE B |
|---|---|---|---|
| No. 1 MFV Open | No. 1 MFV Open Passage to Actuator (Internal) | | X |
| No. 2 MFV Open | No. 2 MFV Open Passage to Actuator (Internal) | | X |
| No. 1 MFV Close | No. 1 MFV Close Passage to Actuator (Internal) | X | |
| No. 2 MFV Close | No. 2 MFV Close Passage to Actuator (Internal) | X | |
| No. 1 MOV Open | No. 1 MOV Open Passage to Actuator (Internal) | | X |
| No. 2 MOV Open | No. 2 MOV Open Passage to Actuator (Internal) | | X |
| No. 1 MOV Close | No. 1 MOV Close Passage to Actuator (Internal) | X | |
| No. 2 MOV Close | No. 2 MOV Close Passage to Actuator (Internal) | X | |
| Gas Generator Valve Open | ICU to No. 2 Hydraulic Mounting Base Joint at IMV Gas Generator Valve Open Port | | X |
| Gas Generator Valve Close | No. 1 Hydraulic Manifold to Gas Generator Valve Hydraulic Control Line Joint (In Seal Plate) | X | |
| Gas Generator Valve Redundant Close | No. 2 Hydraulic Manifold to Redundant Gas Generator Valve Close Control Line Joint (In Seal Plate) | X | |
| Igniter Fuel Supply | EAU to No. 1 Hydraulic Mounting Base Joint at Igniter Fuel Inlet Port (In Seal Plate) | X | |
| Pressure Switch Standby Pressure Supply | EAU to No. 1 Hydraulic Mounting Base Joint at Position Circuit Inlet Port (In Seal Plate) | X | |

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TABLE G-2
OPERATIONAL CONTROL SYSTEM ORIFICING (Cont'd)

| ORIFICE NAME | ORIFICE LOCATION | ORIFICE TYPE A | ORIFICE TYPE B |
|---|---|---|---|
| No. 1 Pressure Switch Sense Line Bleed | Pressure Switch No. 1 to No. 2 Hydraulic Mounting Base Joint (In Seal Plate) | X | |
| No. 2 and No. 3 Pressure Switch Sense Line Bleed | Pressure Switch No. 2 and No. 3 to No. 2 Hydraulic Mounting Base Joint (In Seal Plate) | X | |
| Pressure Switch Test Pressure Bleed | EAU Test Pressure Supply Passage to Pressure Switch Checkout Valve | | X |
| Pressure Switch Test Pressure Supply | EAU Test Pressure Supply Passage to Engine Monitor Valve | | X |
| Pressure Switch Thrust "OK" Pressure Supply | EAU Thrust "OK" Passage to IMV | | X |
| ICU Test Pressure Supply | ICU Test Port Supply Passage (Internal) | X | |
| IMV Test Pressure Bleed | ICU Bleed Passage from IMV Test Supply (Internal) | X | |
| MFV Control Valve Test Pressure Supply | ICU, MFV Control Valve Test Pressure Supply Passage | X | |
| MFV Control Valve Test Pressure Bleed | ICU Bleed Passage from MFV Control Valve Test Pressure Supply | X | |
| Gas Generator Valve Warmant Supply | Gas Generator Valve Hydraulic Control Close Line to Gas Generator Valve Connection (In Seal Plate) | X | |
| Turbopump Warmant Supply | Ground Hydraulic Warmant Supply Line Connection to Turbopump (In Seal Plate) | X | |
| MFV Control Valve Timing Delay | ICU Close Passage From ECU (Internal) | X | |



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TABLE G-3
*SEQUENCE INSTRUMENTATION UNIT*
SIGNAL TYPES AND SOURCES

| EVENT NO. | START SEQUENCE | | TIMING CAPABILITY | |
|---|---|---|---|---|
| | TYPE SIGNAL | SIGNAL SENSE LOCATION | DISCRETE SIGNAL RECEIVED | TIMING INFORMATION OBTAINED |
| -- | Electrical | No. 1 Start Solenoid Current Supply | DC Power Applied to No. 1 Start Solenoid | Start Sequence - Start Signal |
| P1 | Pressure | SIU System Close Port | SIU Start Manifold Vented | Hydraulic Control Valve Open |
| P2 | Pressure | No. 2 MOV Sequence Out Line Joint at Hydraulic Manifold | No. 2 MOV Full Open, Pressure Applied to No. 1 MOV | No. 2 MOV and Sequence Valve Open |
| P3 | Pressure | No. 1 MOV Sequence Out Line Joint at Hydraulic Manifold | No. 1 MOV Open, Pressure Applied to GG Oxidizer Valve | No. 1 MOV Open and Sequence Valve Open |
| P4 | Pressure | Igniter Fuel Control Valve Out Port (Internal to EAU) | Hydraulic Pressure Applied Through Mode Selector Valve of EAU and (a) in checkout mode, test pressure applied to EMU and checks the below pickup pressure setting by lack of pressure switch signals (b) in armed mode, igniter fuel applied to igniter fuel shutoff valve | GG LOX Valve, Sequence Valve and Igniter Fuel Control Valve Open |
| P5 | Pressure | ICU Interface to No. 2 Hydraulic Mounting Base at IMV Outlet Port Upstream of GG Open Orifice | Open Hydraulic Pressure Applied to Gas Generator Valve | IMV Open |
| P6, 12 | Pressure | ICU Interface to No. 2 Hydraulic Mounting Base at MFVCV Outlet Port to No. 2 MFV | Hydraulic Open Pressure Applied to No. 2 MFV | MFVCV Open |
| P7, 8, 10, 11 | Pressure | No. 2 MFV Sequence Valve Out Joint | Hydraulic Open Pressure Applied to No. 1 MFV | No. 2 MFV Open |





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TABLE G-3
SEQUENCE INSTRUMENTATION UNIT
SIGNAL TYPES AND SOURCES (Cont'd)

| EVENT NO. | START SEQUENCE | | TIMING CAPABILITY | |
|---|---|---|---|---|
| | TYPE SIGNAL | SIGNAL SENSE LOCATION | DISCRETE SIGNAL RECEIVED | TIMING INFORMATION OBTAINED |
| P8 | Pressure | EMU Interface to No. 1 Hydraulic Mounting Base at Engine Monitor Valve Open Port | Hydraulic Open Pressure Applied to Engine Monitor Valve | No. 1 MFV Open (Start Sequence Complete) |
| -- | Electrical | Pressure Switches | Pickup Pressure Applied to Pressure Switches | Engine Monitor Valve Open and (a) in checkout complete mode-upper limit of pressure switch pickup pressure (b) in launch commit mode-satisfactory engine thrust for launch |
| -- | Electrical | No. 1 Stop Solenoid Current Supply | DC Power Applied to No. 1 Stop Solenoid | Shutdown Sequence-Start Signal |
| P9 | Pressure | ECU Interface to No. 2 Hydraulic Mounting Base at GG Redundant Valve Close Port | Hydraulic Pressure Applied to GG Valve Redundant Close Actuator | Redundant GG Close Valve Open |
| -- | Electrical | No. 2 Stop Solenoid Current Supply | DC Power Applied to No. 2 Stop Solenoid | Shutdown Sequence-Delayed Start Signal |
| P10 | Pressure | Hydraulic GG Redundant Closing Control Valve Redundant Close Piston Cavity (Internal to ECU) | Redundant Close Pressure Applied to Hydraulic Control Valve Piston GG Redundant Closing Control Piston | Redundant Stop Solenoid and Pilot Valve Open |
| P11 | Pressure | Between GG Open Orifice and Piston at ICU Interface to No. 2 Hydraulic Mounting Base | GG Valve Open Hydraulic Pressure Vented to Return | GG Valve Close |



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TABLE G-3
SEQUENCE INSTRUMENTATION UNIT
SIGNAL TYPES AND SOURCES (Cont'd)

| EVENT NO. | START SEQUENCE | | TIMING CAPABILITY | |
|---|---|---|---|---|
| | TYPE SIGNAL | SIGNAL SENSE LOCATION | DISCRETE SIGNAL RECEIVED | TIMING INFORMATION OBTAINED |
| P13 | Pressure | In No. 1 MOV Open Port Between Open Orifice and Piston | No. 1 MOV Hydraulic Open Pressure Vented to Return | No. 1 MOV Close* |
| P14 | Pressure | In No. 2 MOV Open Port Between Open Orifice and Piston | No. 2 MOV Hydraulic Open Pressure Vented to Return | No. 2 MOV Close* |
| P15 | Pressure | In No. 1 MFV Open Port Between Open Orifice and Piston | No. 1 MFV Hydraulic Open Pressure Vented to Return | No. 1 MFV Close* |
| P16 | Pressure | In No. 2 MFV Open Port Between Open Orifice and Piston | No. 2 MFV Hydraulic Open Pressure Vented to Return | No. 2 MFV Close (Shut-down Sequence Complete) * |
| -- | Electrical | Pressure Switches | Pickup Pressure Not Applied to Pressure Switches | Engine Monitor Valve Close and Loss of Pressure Switch Signals for (a) checkout complete mode or (b) launch commit mode |

* MOV's and MFV's to be staggered to closed position.



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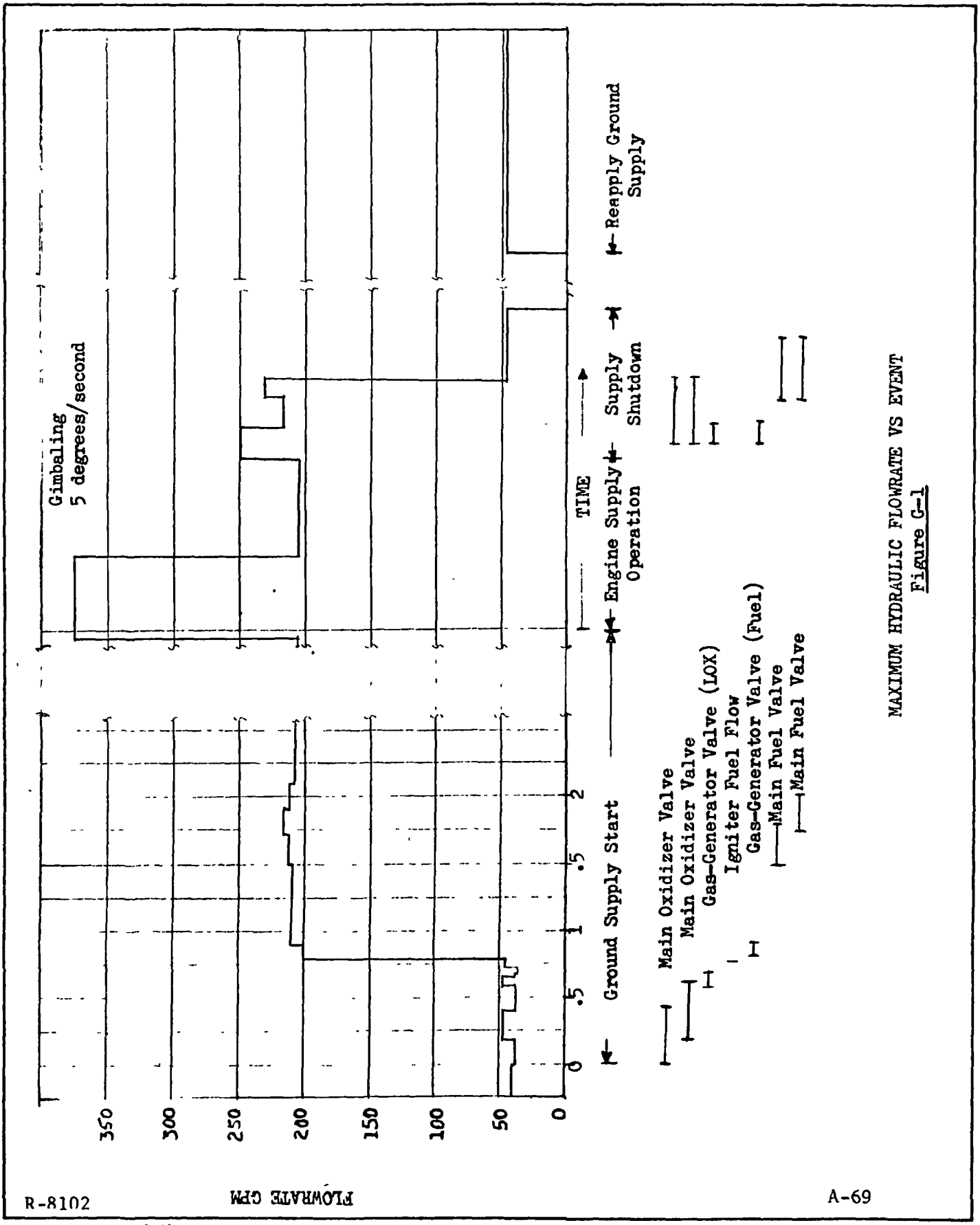
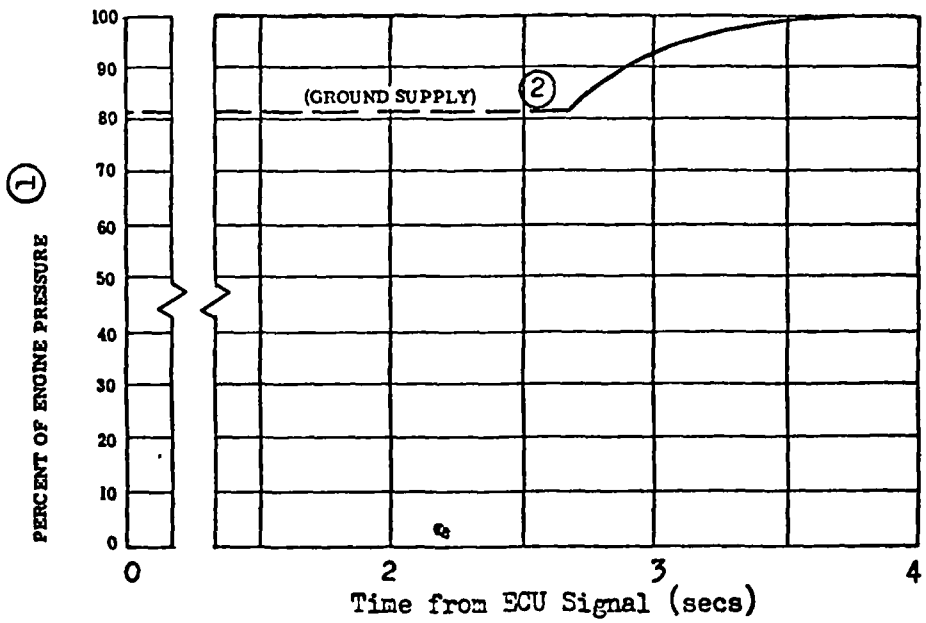



MAXIMUM HYDRAULIC FLOWRATE VS EVENT

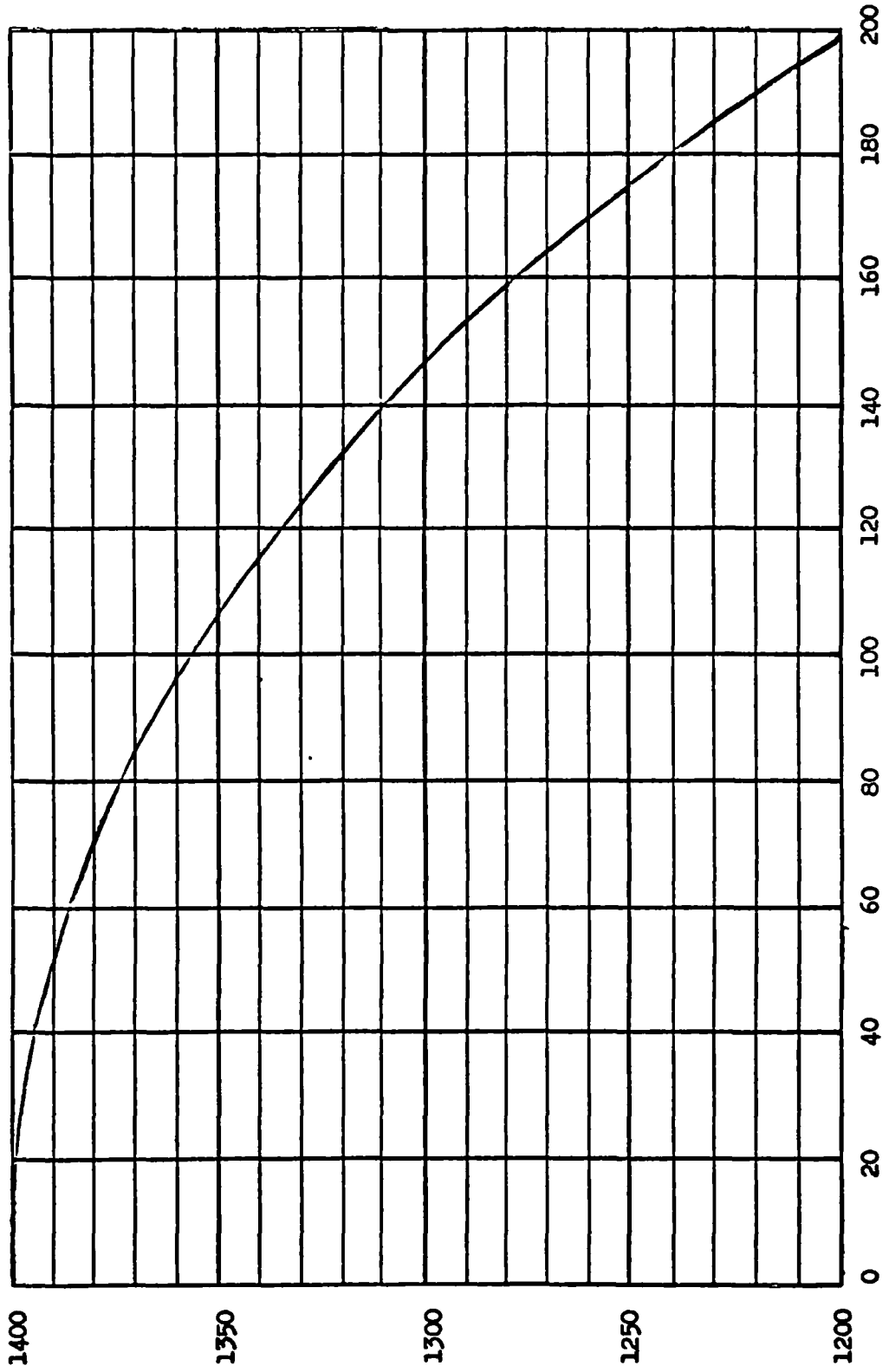
Figure G-1




NOMINAL HYDRAULIC SUPPLY PRESSURE INCREASE CHARACTERISTICS

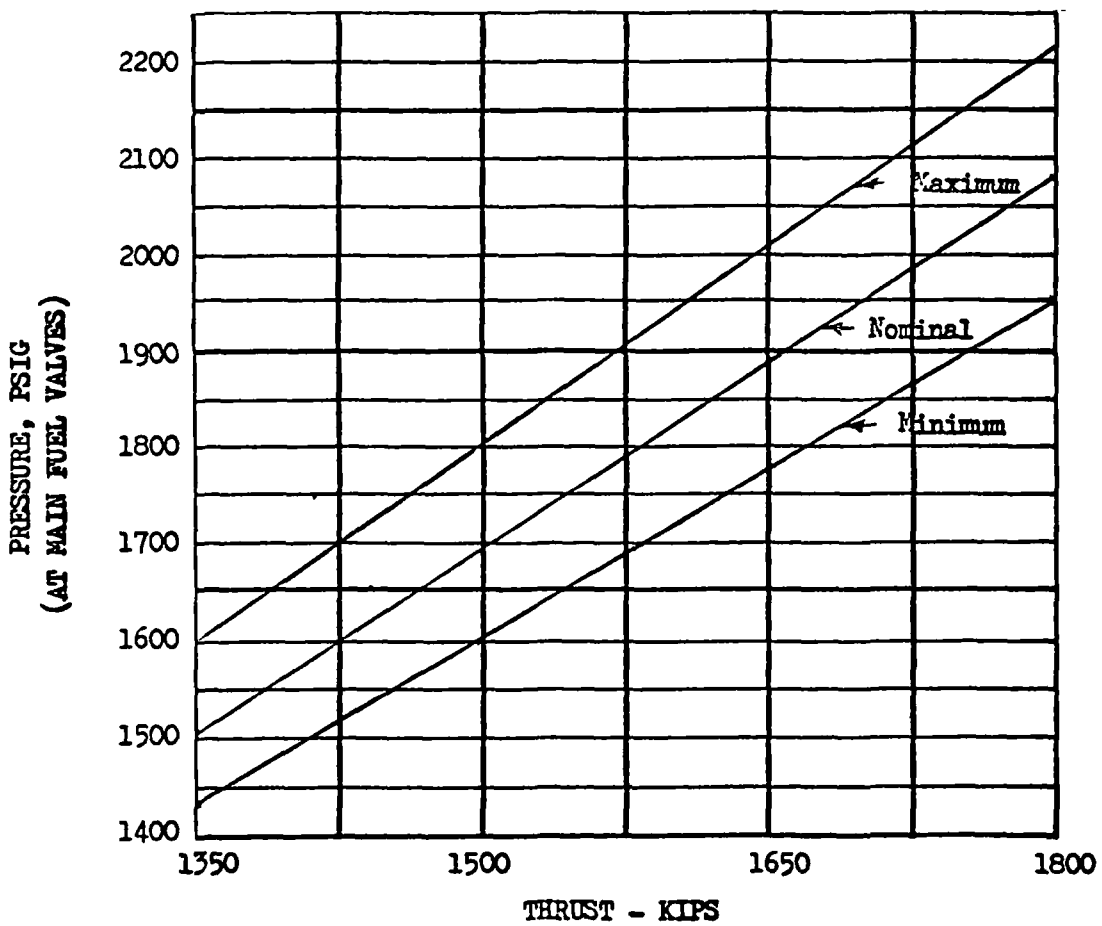
(1) ENGINE SUPPLY PRESSURE MAXIMUM 2300 PSIG, MINIMUM 1300 PSIG

(2) GROUND SUPPLY PRESSURE NOMINAL 1500 PSIG, MINIMUM 1200 PSIG



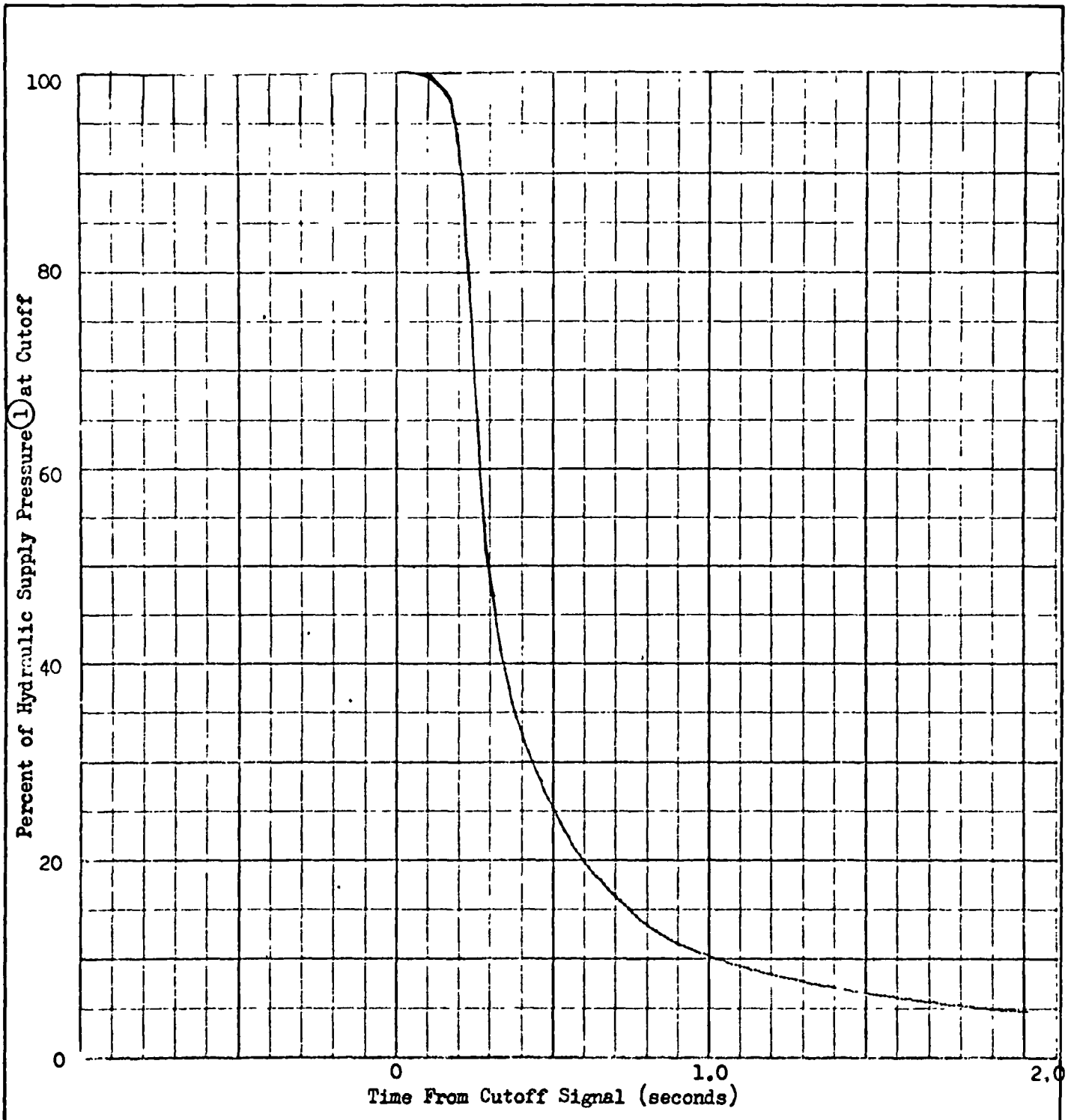

MINIMUM AVAILABLE GROUND HYDRAULIC SUPPLY
(CUSTOMER CONNECT)

FIGURE G-3




ENGINE HYDRAULIC SUPPLY PRESSURE VS THRUST

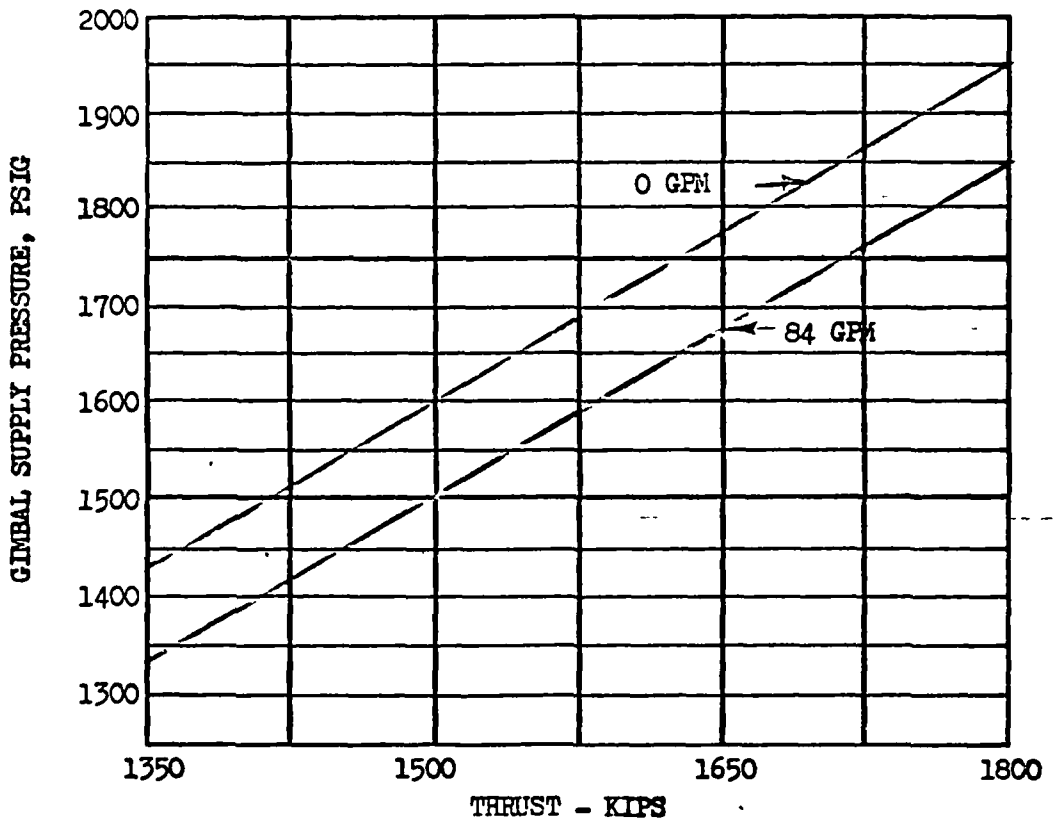
FIGURE G-4




(1) Engine Supply Pressure 2300 PSIA Maximum, 1300 PSIA Minimum

NOMINAL HYDRAULIC SUPPLY PRESSURE DECREASE CHARACTERISTICS

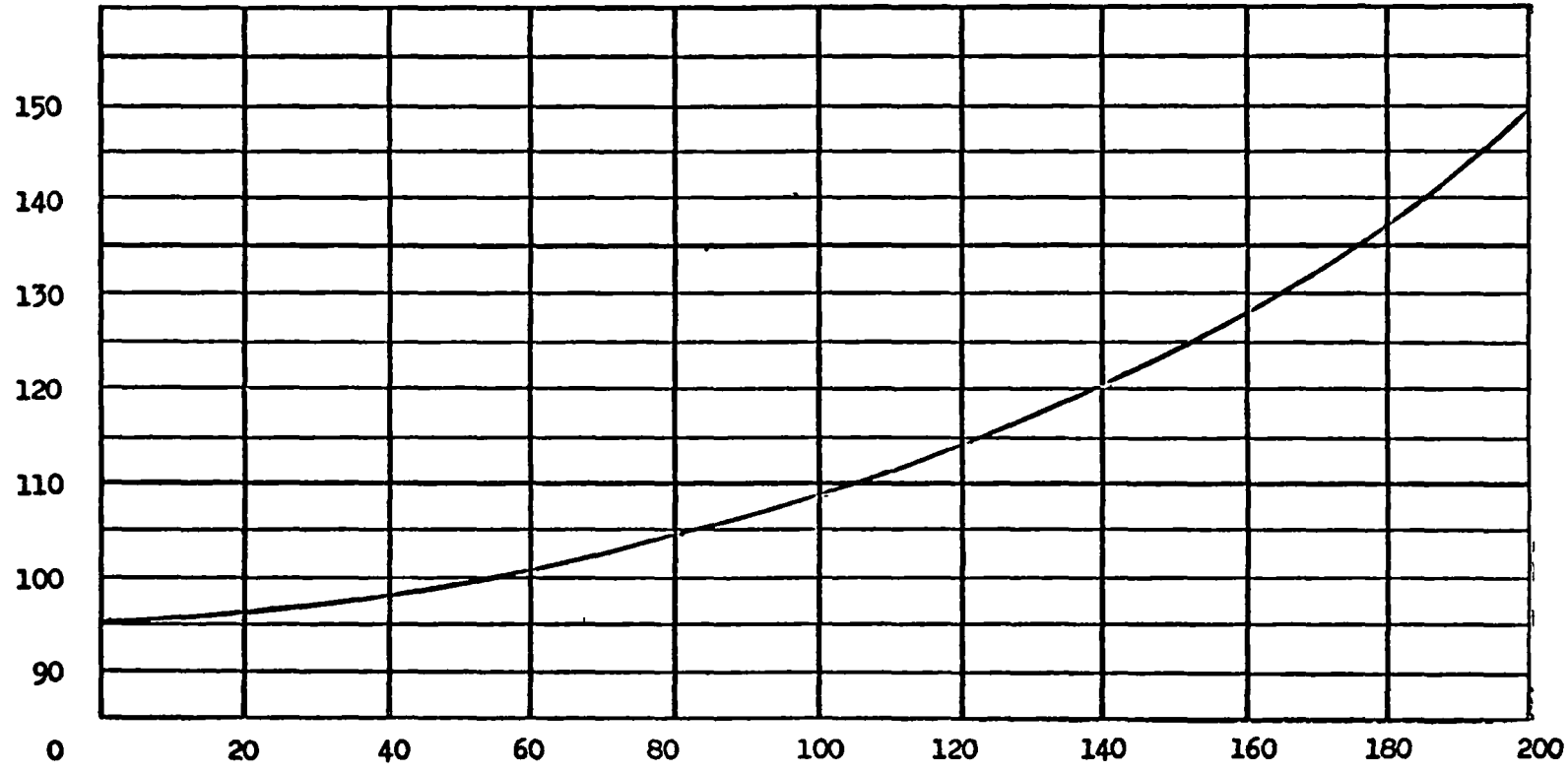
Figure G-5




GIMBAL SUPPLY PRESSURE VS THRUST LEVEL

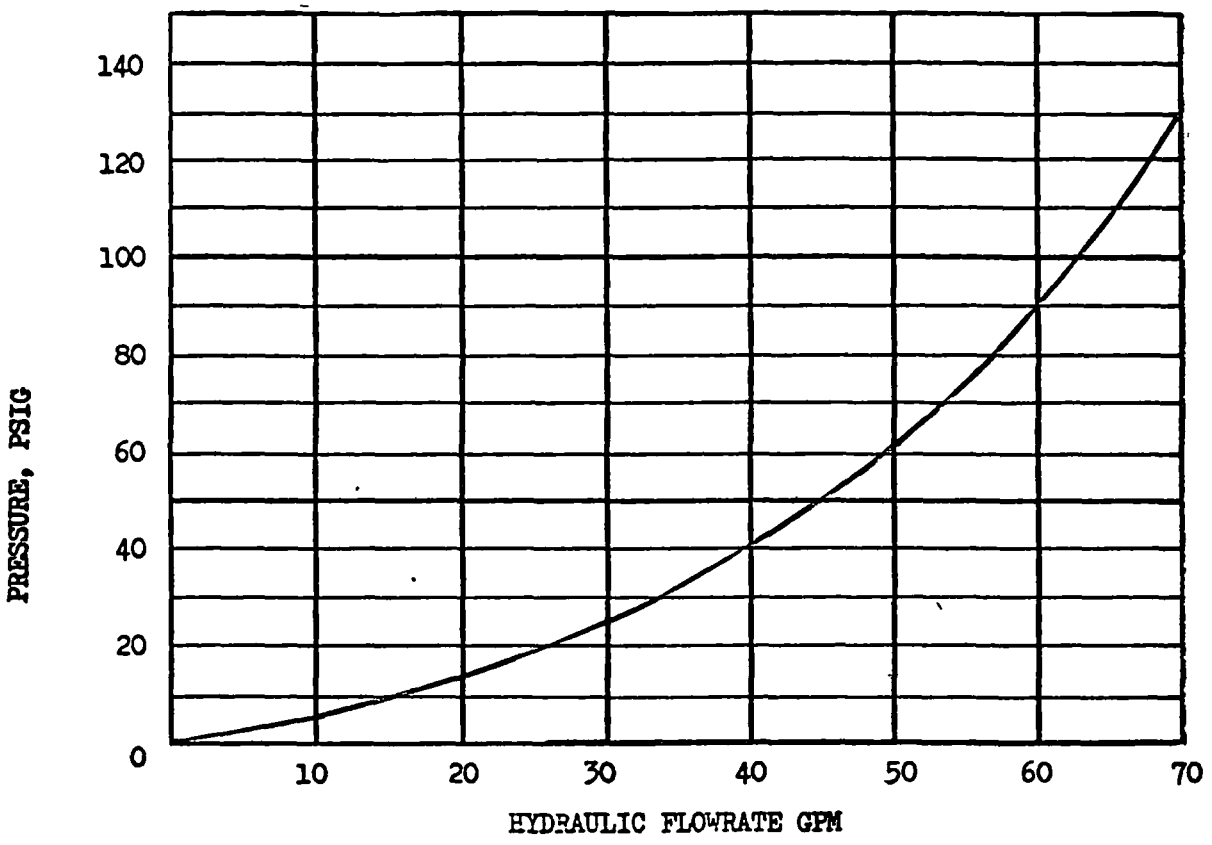
(NO GIMBAL DEMAND - MAXIMUM GIMBAL DEMAND)

FIGURE G-6




ENGINE HYDRAULIC RETURN PRESSURE
(AT ENGINE ARMING UNIT)

FIGURE G-7




GROUND HYDRAULIC RETURN PRESSURE
(AT ENGINE ARMING UNIT)

FIGURE C-8

3.1.1.2.6 IGNITION SYSTEM - The function of the ignition system shall be to provide an ignition source for the propellants in the Thrust System, paragraph 3.1.1.2.1 and the Turbine Drive and Exhaust System, paragraph 3.1.1.2.4. The system shall also provide fuel to sustain ignition. The primary components of the thrust chamber ignition system are the igniter fuel flow control valving, hypergol manifold and cartridge, interconnecting ducting, and the thrust chamber injector. The primary components of the gas generator ignition system are the igniter fuel flow control valving, hypergol supply, interconnect ducting, and the gas generator injector. The detailed quantitative characteristics for the thrust chamber and the gas generator ignition system are tabulated in Table H-1.

3.1.1.2.6.1 FLUIDS HANDLED - The ignition system shall accept RJ-1/RP-1 from the operational control system and shall be compatible with the hypergolic fluid used for establishing ignition. The system shall be compatible with trichloroethylene and gaseous nitrogen.

3.1.1.2.6.2 FLUID FLOWRATES - The flowrates through the thrust chamber and the gas generator ignition system are tabulated in Table H-1.

3.1.1.2.6.3 FLUID PRESSURES - The thrust chamber ignition system shall be capable of accepting pressures in accordance with Table H-1. The ignition system downstream of the closed igniter fuel valve (Operational Control System) shall be designed for a safe operating pressure (checkout with gaseous nitrogen) of 32 psig, and shall meet the requirements of paragraph 3.1.2.7.1.2 Safe Operating Pressure. The system upstream of the closed igniter fuel valve (Operational Control System) shall meet the requirements of paragraph 3.1.1.2.5 Operational Control System. The requirements for the gas generator ignition system are to be determined.

3.1.1.2.6.4 POWER INPUTS - The ignition system shall be provided the following power inputs.

a) MECHANICAL - Mechanical power shall be provided by the operational control system to sequence the ignition system valving to provide the ignition source for the thrust chamber and to secure the ignition system at shutdown. The mechanical power provided to the igniter fuel shutoff valve shall be sufficient to operate the valve to the closed position at all inlet pressures of the valve (which is Operational Control System Return pressure) when the engine is in any mode except Launch Commit. The characteristics of this pressure are described in paragraph 3.1.1.2.5.6 Power Outputs. This

power input shall meet the sequence requirements of paragraph 3.1.1.2.5 Operational Control System.

b) MECHANICAL- Mechanical power shall be provided by the operational control system to sequence the ignition system valving to provide the ignition source for the gas generator and to secure the ignition system at shutdown. This power input shall meet the sequence requirements of paragraph 3.1.1.2.5 Operational Control System.

3.1.1.2.6.5 POWER OUTPUTS - The ignition system shall generate the following outputs.

a) MECHANICAL - The ignition system shall provide an indication of hypergol cartridge installed/not installed to meet the requirements of the operational control system.

3.1.1.2.6.6 IGNITION SYSTEM FUNCTIONAL REQUIREMENTS - The Ignition System shall be designed with the following functional requirements.

a. Actuation of the igniter fuel control valve shall allow ground supplied igniter fuel pressure to rupture the hypergol cartridge diaphragms.

b. The igniter fuel system shall be designed such that the pressure at the thrust chamber hypergol diaphragm does not exceed 475 psig until the gas generator hypergol diaphragm has ruptured and the gas generator igniter fuel line is primed to the gas generator assembly.

c. Priming of the gas generator igniter fuel line shall result in a pressure increase sufficient to rupture the thrust chamber hypergol diaphragm.

d. The hypergol cartridge shall contain a minimum of 37 cubic inches of TEAB. Under normal starting conditions (TBD) cubic inches of hypergol fluid shall flow to the gas generator and (TBD) cubic inches of hypergol fluid shall flow to the thrust chamber. Under the most extreme starting conditions (ignition delay) the cartridge shall provide a minimum of 20 cubic inches of hypergol fluid for thrust chamber ignition. Design of the cartridge used shall provide for retension of all segments of the burst diaphragm.

3.1.1.2.6.7 ALLOWABLE LEAKAGE - The ignition system shall be designed for zero external leakage. Internal leakage shall be

minimized and disposed of within the ignition system. Propellant valves shall meet the requirements of paragraph 3.1.2.7.2.14 Propellant Valve Leakage.

3.1.1.2.6.8 DRAINAGE - The ignition system shall be capable of being completely drained of residual fluids in accordance with paragraphs 3.1.2.2.2 Service and Access, 3.1.2.7.1.4 Live Hypergol Removal, and 3.1.2.7.2.15, Propellant Draining.

The system should be designed without fluid traps to enhance removal of fluids with a servicing purge. A single servicing purge connect point should be capable of simultaneously servicing both the thrust chamber and gas generator ignition systems downstream of the igniter fuel shutoff valve. Servicing of either system shall not require opening of any propellant valve. The gas generator and thrust chamber igniter fuel systems downstream of the servicing port shall be designed to be free draining to the faces of the respective injectors.

3.1.1.3.6.9 SYSTEM PRIMING - The ignition system shall provide uniform fluid priming characteristics at the face of the thrust chamber injector. Differential prime time between all system outlets at the face of the injector shall not exceed TBD seconds.

3.1.1.2.6.10 REDUNDANCY REQUIREMENTS - The system shall provide redundant ignition sources to each thrust chamber injector compartment and to the gas generator combustor.

3.1.1.2.6.11 ORIFICING REQUIREMENTS - The system shall be designed to provide a variable flow control orifice to be located in the seal plate at the interface between the gas generator igniter fuel line and the gas generator assembly and a variable flow control orifice to be located in the seal plate at the interface between the engine arming unit and the No. 1 Mounting Base.

TABLE H-1
IGNITION SYSTEM CHARACTERISTICS

| SUBSYSTEM | PARAMETER | UNITS | OPERATING CONDITIONS NOMINAL | MINIMUM | MAXIMUM |
|---|---|---|---|---|---|
| Flow Control Valving (EAU) | Flowrate | lbs/sec | 20 | 10.1 | 21 |
| | Pressure (Inlet) | psia | 1500 | 1000 | 4000 |
| | Temperature | °F | 70 | 35 | 150 |
| | Fluid Resistance | [11] | 28 | 24 | 32 |
| Hyper-gol Manifold | Flowrate | lbs/sec | 20 | 10.1 | 21 |
| | Pressure | psia | 1500 | 1000 | 4000 |
| | Fluid Resistance | [11] | 10 | 7 | 13 |
| Hypergol Cartridge | Flowrate | lbs/sec | 20 | 10.1 | 21 |
| | Pressure | psia | 1500 | 1000 | 3000[12] |
| | Fluid Resistance | [11] | 38 | 33 | 43 |
| Tc Fuel Line | Flowrate | lbs/sec | 19.84 | 10.0 | 20.8 |
| | Fluid Resistance | [11] | 45 | 29 | 51 |
| Tc Orifice | Flowrate | lbs/sec | 19.84 | 10.0 | 20.8 |
| | Fluid Resistance | [11] | 0.0 | 0.0 | 20.8 |
| Tc Injector | Flowrate | lbs/sec | 19.84 | 10.0 | 20.8 |
| | Fluid Resistance | [11] | 69 | 60 | 72 |
| GG Fuel Line | Flowrate | lbs/sec | 0.16 | 0.10 | 0.20 |
| | Fluid Resistance | [11] | 7100 | 6200 | 8000 |
| GG Orifice | Flowrate | lbs/sec | 0.16 | 0.10 | 0.20 |
| | Fluid Resistance | [11] | 1,200,000 | 700,000 | 1,400,000 |
| GG Injector | Flowrate | lbs/sec | 0.16 | 0.10 | 0.20 |
| | Fluid Resistance | [11] | 427,000 | 372,000 | 482,000 |
| Hypergol Cartridge | Installation (MECH) | Pounds | 40 | 35 | 45 |
| | | Inches | 1.125 | 1.075 | 1.175 |
| | Burst Pressure | | | | |
| | GG Upstream | Psi | 500 | 425 | 525 |
| | GG Downstream | Psi | 350 | 275 | 375 |
| | TC Upstream | Psi | 500 | 425 | 525 |
| | TC Downstream | Psi | 350 | 275 | 375 |

[11] $sec^2/in^2\text{-}ft^3$
[1] applies throughout downstream systems

3.1.1.2.7 THRUST CONTROL SYSTEM - The function of the thrust control system shall be to control engine thrust within the range specified in paragraph 3.1.1.1.2.2 Thrust Adjustment Capability by controlling propellant flow within the turbine drive and exhaust system. The primary components of the thrust control system shall include the throttle valving actuator, position feedback, the throttle valve controller, the thrust control system programmer, and the thrust profile generator. This system is described in Figure J-1 and Table J-1.

3.1.1.2.7.1 POWER INPUTS - The thrust control system shall be supplied with the following inputs.

a. ELECTRICAL - The thrust control system shall be supplied with 150 watts of power at 28 vdc.

b. FLUID - The thrust control system shall be supplied with power from the fuel feed system indicating thrust level.

c. THRUST PROFILE - The thrust control system may be supplied with a desired thrust profile from the vehicle/facility.

3.1.1.2.7.2 POWER OUTPUTS - The following outputs shall be supplied by the thrust control system.

a. MECHANICAL - Mechanical power shall be supplied to the turbine drive and exhaust system to position the thrust control valving in accordance with the fluid resistance requirements of Table F-1 as dictated by the thrust profile generator. This power output shall also meet the requirements of a maximum slew rate of TBD seconds.

3.1.1.2.7.3 THRUST CONTROL SYSTEM FUNCTIONAL REQUIREMENT - The thrust control system shall be capable of the following functional requirements.

a. The thrust control system shall be designed to utilize either engine internally generated pre-programmed desired thrust profile, a vehicle generated desired thrust profile, or be capable of selecting either of the inputs.

TABLE J-1

THRUST CONTROL SYSTEM

A. Thrust Profile Generator

1. Generate or accept Non-Linear Thrust Profile

B. Oxidizer Programmer/Thrust Controller

1. Manual Oxidizer Valve Position Control
2. Four Pre-set Thrust Levels
3. Accept Non-Linear Thrust Profile from Item A
4. Control Thrust System Stability
5. Indicate Oxidizer Valve Position
6. Provide Means for System Calibration

C. Oxidizer Valve Position Controller

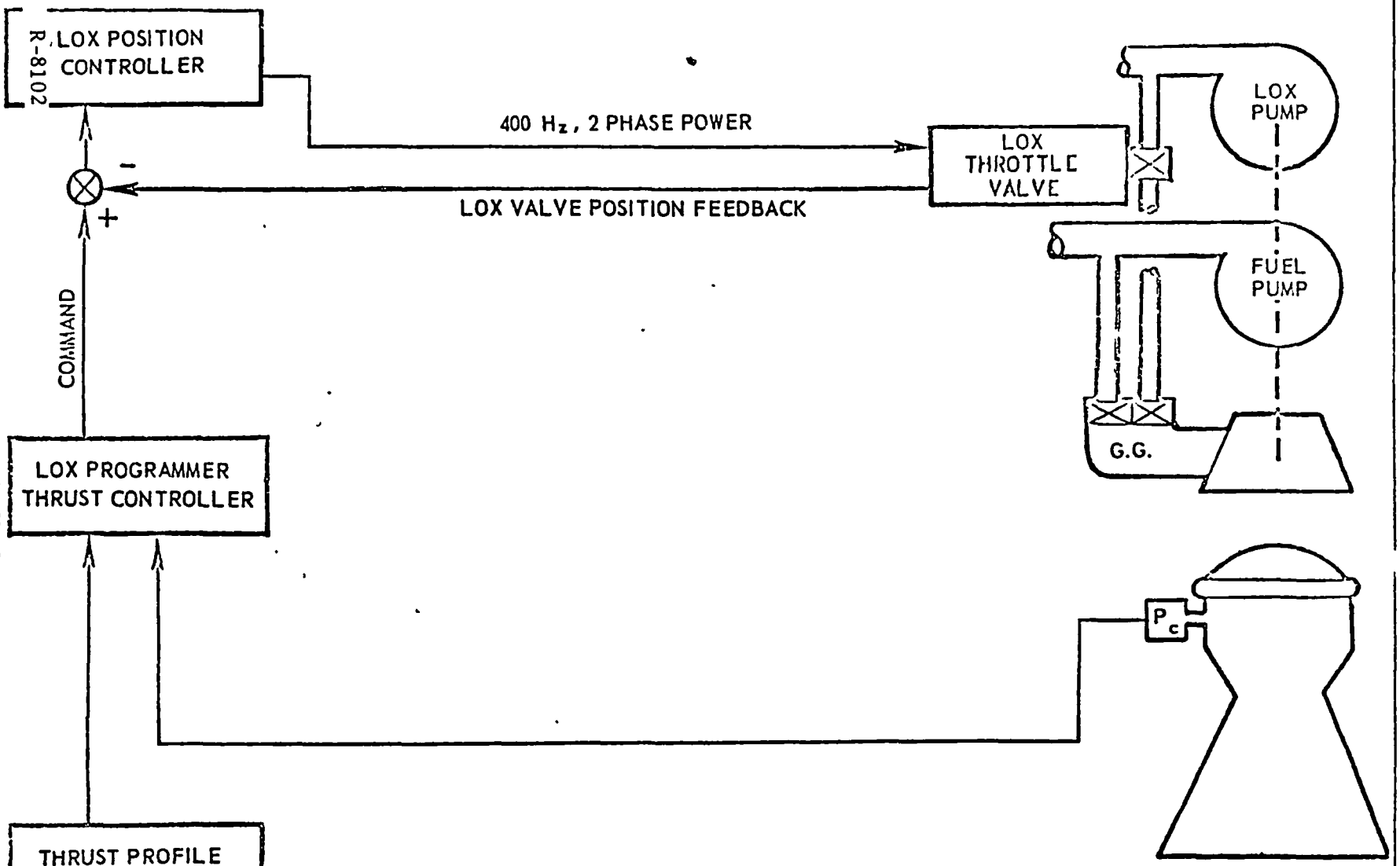
1. Generate Power to Drive Oxidizer Valve Actuator
2. Accept Oxidizer Valve Position Feedback
3. Accept Command Signal from Item B

D. Oxidizer Valve Position Actuator/Feedback

1. Position Fluid Portions of Throttle Valve as required
2. Accept Power Input from Item C
3. Provide Feedback for Item C

E. Thrust Level Feedback

1. Provide Indication/Feedback of Engine Thrust Level to Item B




THRUST CONTROL SYSTEM SCHEMATIC

Figure J-1



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3.1.1.2.8 INSTRUMENTATION SYSTEMS - The engine system shall be designed to provide the capability for instrumenting selected internal operating parameters to adequately define engine operation and performance.

The Instrumentation system consists of Flight Instrumentation, Stage Static/Acceptance Test Instrumentation and Special Test Instrumentation. The Flight Instrumentation system in turn consists of two pressure transducers, a Sequence Instrumentation Unit signal generator, a tachometer signal generator, interconnecting harnesses and fluid connections. The Stage Static/Acceptance Test Instrumentation and Special Test Instrumentation consists of porting in the fluid systems, plumbing and provisions for attaching transducers for monitoring the engine parameters.

Requirements are also described for the Signal Conditioning, Transmitting, Recording system needed for adequate analysis of engine operation.

3.1.1.2.8.1 FLIGHT INSTRUMENTATION - The flight instrumentation system shall be designed to provide indications of the internal operating parameters listed in Table K-1. In addition to the instrumentation in Table K-1 the requirements of paragraph 10-1 shall be provided by the stage.

TABLE K-1
FLIGHT INSTRUMENTATION REQUIREMENTS

| Parameter | Source/ Precision | Frequency Response | Range |
|---|---|---|---|
| Combustion Chamber Pressure[11] | TBD | 0-3000 Hz | 0-1500 psia |
| Fuel Injection Pressure[11] | TBD | 0-3000 Hz | 0-1500 psia |
| Sequence Instrumentation Unit Output | TBD | 0-3000 Hz | 0-5 vdc |
| Turbopump Speed [11] | TBD | 0-3000 Hz | 0-6500 rpm |

[11] Two of these parameters to be selected for redundant thrust control system input (feedback) in addition to providing indication of parameters levels.

3.1.1.2.8.1.1 FLIGHT INSTRUMENTATION POWER INPUTS - The Instrumentation System shall receive TBD watts of electrical power at 24 to 36 vdc. This power is to be used for transducer excitation.

3.1.1.2.8.1.2 FLIGHT INSTRUMENTATION POWER OUTPUTS - The flight instrumentation pressure transducers shall produce an output potential of 0 to 5 vdc with a maximum output resistance of 5000 ohms.

3.1.1.2.8.1.3 FLIGHT INSTRUMENTATION PORTS - The engine system shall be designed to provide Flight Instrumentation porting conforming to TBD for pressure transducers and TBD for the tachometer signal generator.

3.1.1.2.8.2 STAGE STATIC TEST INSTRUMENTATION - The Engine System shall be designed to provide the porting, transducer mounting, and plumbing required to instrument the parameters listed in Table K-2. The engine shall be designed to utilize the requirements of this paragraph along with Flight Instrumentation in accordance with paragraph 3.1.1.2.8.1 Flight Instrumentation, and Stage/Facility supplied Instrumentation in accordance with paragraph 10.1 Stage/Facility Supplied Instrumentation for static and acceptance testing.

TABLE K-2
STAGE STATIC/ACCEPTANCE TEST INSTRUMENTATION

| | | Plumbing Requirements | | |
|---|---|---|---|---|
| Parameters | Boss Location | Plumb To Panel | Engine Mounted Transducer | Plug Port |
| #2 Fuel Pump Outlet Pressure | #2 Fuel Duct | | X | |
| #2 LOX Pump Outlet Pressure | #2 LOX Duct | | X | |
| Turbine Outlet Pressure | Turbine Exhaust Duct | | X | |
| Turbine Inlet Pressure | Gas Generator Combustor | | X | |
| Turbine Inlet Temperature | Turbine Manifold | | X | |
| Oxidizer Dome Vibration | Oxidizer Dome | | X | |

3.1.1.2.8.2.1 STAGE STATIC/ACCEPTANCE TEST INSTRUMENTATION PORTS - The engine system shall be designed to provide Stage Static/-Acceptance test instrumentation porting conforming to RP260-1001, for pressure and temperature instrumentation, and to TBD for vibration instrumentation.

3.1.1.2.8.3 SPECIAL TEST INSTRUMENTATION - Not applicable

3.1.1.2.8.4 SIGNAL CONDITIONING AND TRANSMITTING REQUIREMENTS - The engine system shall be designed based on the Stage or facility supplying the Signal Conditioning and Transmitting Equipment and where applicable the recording equipment.

3.1.1.2.9 VEHICLE/STAGE SERVICE SYSTEMS - The description and requirements for this system will be provided in later revisions.

3.1.2 OPERABILITY

3.1.2.1 RELIABILITY - To be determined.

3.1.2.2 MAINTAINABILITY - The engine system shall be designed to be compatible with existing Ground Support Equipment as specified in R3896-5 F-1 Engine Ground Support Equipment. All exceptions to this requirement will be specified in this paragraph.

3.1.2.2.1 MAINTENANCE AND REPAIR CYCLES - The engine system shall be designed to meet the requirements of a maintenance and checkout plan based on operational need and consistent with quality control requirements. Consistency of tests and criteria shall be established for all levels of operation from the component procurement criteria, through component assembly and checkout, Engine assembly and Pre-Acceptance checkout, Engine acceptance, engine post-acceptance checkout, engine receival inspection, stage assembly and checkout, stage static test, stage post-static test checkout, and launch vehicle assembly, to pre-launch checkout. Primary consideration in establishing the type of test, type of fluid, fluid temperature and pressure, allowable leakage, and tolerance control shall be given to the operational simulation. Demonstrated change in characteristics with usage and instrumentation accuracy and precision shall also be utilized.

3.1.2.2.1.1 COMPONENT LEVEL LEAK TEST REQUIREMENTS - Components and subsystems shall be designed to include the following leak check criteria as a minimum during component and subsystem checkout.

a. Component and subsystem leak checks must be as stringent as system level leak checks.

b. Test conditions per component and subassembly leak tests shall be representative of steady state operation and encompass the range of operational values. Table M-1 presents test fluids and pressures which satisfy this requirement.

c. All leak checks shall require application of the test fluid at test pressure for a minimum of two minutes. No maximum application time shall be stated.

d. Where no leakage allowed is expressed or implied, this shall mean

1. Monitored leakage is at or below the minimum detectable leakage rate of system level leakage monitoring equipment (0.25 scim).

or that

2. Leak tests accomplished with leak test solution does not exceed fuzz leakage.

1. Fuzz Leakage - Formation of bubbles in a leak test solution which do not exhibit growth with time for a period of five minutes.

e. No external leakage shall be allowed.

f. Allowable internal leakage shall be minimized consistent with the following:

1. Leakage tests in the hydraulic, fuel, and oxidizer systems shall provide assurance of no liquid leakage in operational modes.

2. Leakage tests in the fuel and oxidizer systems shall provide assurance that maximum allowable stage tank bleed down rates will not be exceeded.

g) All component interface sealing surfaces integrity shall be verified during component leak tests to provide confidence that the sealing surface will be satisfactory when installed in the engine system.

h) All data resulting from function checkout tests shall be recorded.

3.1.2.2.2 SERVICE AND ACCESS - The engine system shall be designed to comply with the service and access provisions of this section.

3.1.2.2.2.1 FLUID SYSTEM DRAINAGE - The engine system shall be designed to be drained of all fluids with a minimum number of drainage service connect points.

a. OXIDIZER SYSTEM - The oxidizer system shall meet the requirements of paragraph 3.1.2.7.2.15, Propellant Draining, and also be capable of fluid removal upstream of the propellant valves by normal boiloff. The engine attitude for all draining operations shall be nozzle down with the thrust chamber centerline within 3 degrees of true vertical.

b. FUEL SYSTEM - The fuel system shall meet the requirements of paragraph 3.1.2.7.2.15, Propellant Draining and shall also be designed to be capable of self draining (no flushing or purging). Fuel

drainage upstream of propellant valves shall be accomplished through quick disconnects when it is required to violate the fluid system integrity. The engine attitude for all draining operations shall be nozzle down with the thrust chamber centerline within 3 degrees of true vertical.

c. OPERATIONAL CONTROL SYSTEM - The operational control system shall be designed to provide for removal of fluid (self draining and/or purging) from the fluid passages for component removal and/or replacement. All actuators and control system elements shall be in the de-energized position with hydraulic supply pressure not applied. The engine attitude for operational system drainage shall be as follows:

1. Vertical - The engine shall be nozzle down and the thrust chamber centerline[1] within 3 degrees of true vertical.

2. Horizontal - The five engine positions shall all have the Y axis[1] horizontal and either the Zg axis[1] vertical (positive direction up), or the Zg axis vertical (negative direction up), or the Xg axis[1] vertical (positive direction up), or the Xg axis vertical (negative direction up), or the Z axis[1] vertical (positive direction up).

3.1.2.2.2.2 SERVICING AND PURGING - The engine system and components servicing and purging passages shall be designed to preclude acoustical coupling with engine fluid systems during engine operation.

3.1.2.3 USEFUL LIFE - The engine system shall be designed to have a service life[1] of (TBD) Starts and (TBD) seconds of Total operating time. The service life includes those starts and operating time required for acceptance testing.

3.1.2.4 ENVIRONMENT - The engine system shall be designed to start, operate and shutdown during or after exposure to the environmental requirements listed herein.

3.1.2.4.1 STANDBY EXPOSURE ENVIRONMENT - The engine system shall meet the following criteria.

a. The engine system; with or without thermal insulation and supplied with fluids in accordance with paragraphs 3.2.1.2.1.4 Hypergol Fluid, 3.2.1.2.1.1 Nitrogen, 3.2.1.2.1.5 Hydraulic

Control Fluid, 3.2.1.2.1.6 Thrust Chamber Prefill Fluid, and 3.2.1.2.1.2 Fuel; shall be designed not to suffer any detrimental effects when exposed to an ambient temperature range of -30F to plus 130F for TBD hours.

b. The engine system; without thermal insulation and supplied with fluids in accordance with paragraphs 3.2.1.2.1.4 Hypergol fluid, 3.2.1.2.1.1 Nitrogen, 3.2.1.2.1.5 Hydraulic Control Fluid, 3.2.1.2.1.6 Thrust Chamber Prefill Fluid, 3.2.1.2.1.2 Fuel and 3.2.1.2.1.3 Oxidizer; shall be designed not to suffer any detrimental effects when exposed to an ambient temperature range of -30F to 130F for TBD hours.

c. The engine system; with thermal insulation and supplied with fluids in accordance with paragraphs 3.2.1.2.1.4 Hypergol Fluid, 3.2.1.2.1.1 Nitrogen, 3.2.1.2.1.5 Hydraulic Control Fluid, 3.2.1.2.1.6 Thrust Chamber Prefill Fluid, 3.2.1.2.1.2 Fuel, and 3.2.1.2.1.3 Oxidizer; shall be designed not to suffer any detrimental effects when exposed to an ambient temperature range of plus 28F to plus 130F for TBD hours.

3.1.2.4.2 STARTING ALTITUDE - The engine system shall be designed to be started at any altitude from zero to 10,000 feet.

3.1.2.4.4 GROUND OPERATING ENVIRONMENT - The engine system shall be designed to meet the following requirements during captive testing.

a. The engine system without thermal insulation shall be capable of operation and shutdown during and after exposure in accordance with paragraphs 3.1.2.4.1 a. and 3.1.2.4.1 b. Standby exposure environment when supplied with inputs in accordance with paragraphs 3.2.1.2 Detail Interface Definition when subjected to applicable loading in accordance with paragraph 3.1.2.4.6 Mechanical Loading Environment.

b. The engine system with thermal insulation shall be capable of operation and shutdown during and after exposure in accordance with paragraph 3.1.2.4.1 a. and 3.1.2.4.1 c. Standby Exposure Environment providing that the ambient temperature within the engine insulation cocoon does not exceed that resulting from flight thermal environment in accordance with paragraph 3.1.2.4.5 Flight Operating Environment throughout the

engine effective duration in accordance with paragraph 3.1.1.1.1 Effective Duration when supplied with inputs in accordance with paragraph 3.2.1.2 Engine Interface Definition and subjected to applicable loading in accordance with paragraph 3.1.2.4.6 Mechanical Loading Environment. The engine as defined in paragraph 3.3.1.1 Drawings shall suffer no detrimental effects providing that the ambient temperature is in accordance with paragraphs 3.1.2.4.1 a. and 3.1.2.4.1 c. Standby Exposure Environment subsequent to engine shutdown.

3.1.2.4.5 FLIGHT OPERATING ENVIRONMENT - The engine system shall be designed to be capable of operation and shutdown after exposure in accordance with paragraph 3.1.2.4 Standy Exposure Environment and during exposure to all pressure altitudes and the flight thermal environment presented in Figures N-1 and N-2; for the effective duration in accordance with paragraph 3.1.1.1.1 Effective Duration; when supplied with inputs in accordance with paragraph 3.2.1.2 Engine Interface Definition and when subjected to loading in accordance with paragraph 3.1.2.4.6 Mechanical Loading Environment.

3.1.2.4.6 MECHANICAL LOADING ENVIRONMENT - The engine system with thermal insulation shall be designed to withstand, without permanent deformation or failure, the maximum forces resulting from all combinations of the following flight and operating mechanical loading conditions. The maximum load for which each external connect point is designed shall be in accordance with paragraph 3.2.1 Interface Requirements.

a. PERFORMANCE LEVEL LOADS - The engine shall be designed to withstand loads resulting from operation of an engine calibrated with the performance limits of paragraph 3.1.1.1.2 Steady State Performance Ratings at all pressure altitudes when supplied propellants within the acceptable pump inlet propellant temperature-pressure regions in accordance with paragraph 3.2.1.2.1 Fluid Inputs for the respective effective duration of paragraph 3.1.1.1.1 Effective Duration. Internal engine operating environment (e.g. pressure, flowrates) is presented in paragraph 3.1.1.2 Secondary Performance Characteristics.

b. VIBRATION LOADS - The engine shall be designed to be capable of withstanding all self induced vibrations encountered during operation within the vibration range of 35g's rms (1225 g's mean

squared) within the frequency range of 10 to 5,000 Hz, as measured by thrust chamber dome mounted accelerometers and reduced to a time averaged value[1] without detrimental effects.

All components and sub-systems shall be designed to withstand the engine vibration environment. This environment is divided into ten areas and the vibration levels and frequencies are specified herein for each area.

ENVIRONMENTAL AREA NO. 1 - Combustion Chamber, Fuel inlet manifold to throat.

SINUSOIDAL SWEEP CRITERIA

| | | | |
|---|---|---|---|
| 5 | to | 23 Hz | @ 0.3 inch D.A. |
| 23 | to | 47 Hz | @ 8 g's peak |
| 47 | to | 75 Hz | @ 0.07 inch D.A. |
| 75 | to | 315 Hz | @ 20 g's peak |
| 315 | to | 495 Hz | @ 0.004 inch D.A. |
| 495 | to | 2000 HZ | @ 50 g's peak |

RANDOM DWELL CRITERIA
Random Levels

| | | | |
|---|---|---|---|
| 20 | to | 450 Hz | @ 0.2 $(grms)^2/Hz$ |
| 450 | to | 500 Hz | @ 90 db/octave |
| 500 | to | 600 Hz | @ 5.0 $(grms)^2/Hz$ |
| 600 | to | 650 Hz | @ -120 db/octave |
| 650 | to | 850 Hz | @ 0.2 $(grms)^2/Hz$ |
| 850 | to | 900 Hz | @ +60 db/octave |
| 900 | to | 2000 Hz | @ 0.6 $(grms)^2/Hz$ |

Sinusoids

1140 Hz @ 15g peak
Total Composite Level = 39.6 grms

ENVIRONMENTAL AREA NO. 2 - Turbopump - Fuel pump discharge flanges.

SINUSOIDAL SWEEP CRITERIA

| | | | |
|---|---|---|---|
| 5 | to | 23 Hz | @ 0.3 inch D.A. |
| 23 | to | 140 Hz | @ 8 g peak |
| 140 | to | 310 Hz | @ 0.008 inch D.A. |
| 310 | to | 2000 Hz | @ 40 g peak |

RANDOM DWELL CRITERIA
Random Levels

20 to 210 Hz @ 0.1 (grms)$^2$/Hz
210 to 300 Hz @ +12 db/octave
300 to 505 Hz @ 0.4 (grms)$^2$/Hz
505 to 550 Hz @ +45 db/octave
550 to 650 Hz @ 1.4 (grms)$^2$/Hz
650 to 750 Hz @ -42 db/octave
750 to 1210 Hz @ 0.2 (grms)$^2$/Hz
1210 to 1400 Hz @ +27 db/octave
1400 to 2000 Hz @ 0.75 (grms)$^2$/Hz

Sinusoids

190 Hz @ 10 g peak
570 Hz @ 40 g peak
1140 Hz @ 30 g peak

Total Composite Level = 47.7 grms

ENVIRONMENTAL AREA NO. 3 - Turbopump - Oxidizer pump discharge flanges

SINUSOIDAL SWEEP CRITERIA

5 to 23 Hz @ 0.3 inch D.A.
23 to 320 Hz @ 8 g peak
320 to 675 Hz @ 0.0015 inch D.A.
675 to 2000 Hz @ 35 g peak

RANDOM DWELL CRITERIA
Random Levels

20 to 200 Hz @ 0.1 (grms)$^2$/Hz
200 to 300 Hz @ +9 db/octave
300 to 1100 Hz @ 0.35 (grms)$^2$/Hz
1100 to 1310 Hz @ +24 db/octave
1310 to 1600 Hz @ 1.4 (grms)$^2$/Hz
1600 to 1800 Hz @ -36 db/octave
1800 to 2000 Hz @ 0.35 (grms)$^2$/Hz

Sinusoids

570 Hz @ 30 g peak
1140 Hz @ 35 g peak

Total Composite Level = 46.6 grms

ENVIRONMENTAL AREA NO. 4 - Gas Generator

SINUSOIDAL SWEEP CRITERIA

| | | | |
|---|---|---|---|
| 5 | to | 23 | Hz @ 0.3 inch D.A. |
| 23 | to | 140 | Hz @ 8 g peak |
| 140 | to | 310 | Hz @ 0.008 inch D.A. |
| 310 | to | 2000 | Hz @ 40 g peak |

RANDOM DWELL CRITERIA
Random Levels

| | | | |
|---|---|---|---|
| 20 | to | 450 | Hz @ 0.2 $(grms)^2/Hz$ |
| 450 | to | 500 | Hz @ +45 db/octave |
| 500 | to | 600 | Hz @ 1.0 $(grms)^2/Hz$ |
| 600 | to | 720 | Hz @ -27 db/octave |
| 720 | to | 1400 | Hz @ 0.2 $(grms)^2/Hz$ |
| 1400 | to | 1550 | Hz @ +33 db/octave |
| 1550 | to | 2000 | Hz @ 0.6 $(grms)^2/Hz$ |

Sinusoids

| | | | |
|---|---|---|---|
| 100 | Hz | @ 5 | g peak |
| 130 | Hz | @ 5 | g peak |
| 1140 | Hz | @ 40 | g peak |

Total Composite Level = 39.4 grms

ENVIRONMENTAL AREA NO. 5 - Main Fuel Valves

SINUSOIDAL SWEEP CRITERIA

| | | | |
|---|---|---|---|
| 5 | to | 31 | Hz @ 0.3 inch D.A. |
| 31 | to | 385 | Hz @ 15 g peak |
| 385 | to | 585 | Hz @ 0.002 inch D.A. |
| 585 | to | 2000 | Hz @ 35 g peak |

RANDOM DWELL CRITERIA
Random Levels

| | | | |
|---|---|---|---|
| 20 | to | 400 | Hz @ 0.2 $(grms)^2/Hz$ |
| 400 | to | 500 | Hz @ +18 db/octave |
| 500 | to | 750 | Hz @ 0.75 $(grms)^2/Hz$ |
| 750 | to | 935 | Hz @ -12 db/octave |
| 935 | to | 1720 | Hz @ 0.3 $(grms)^2/Hz$ |
| 1720 | to | 2000 | Hz @ +24 db/octave |
| | | 2000 | Hz @ 1.0 $(grms)^2/Hz$ |

Sinusoids

| | | | |
|---|---|---|---|
| 95 | Hz | @ 5 | g peak |
| 570 | Hz | @ 35 | g peak |
| 1140 | Hz | @ 10 | g peak |

Total Composite Level = 38.4 grms

ENVIRONMENTAL AREA NO. 6 - Main Oxidizer Valves

SINUSOIDAL SWEEP CRITERIA

| | | | |
|---|---|---|---|
| 5 | to | 32 | Hz @ 0.3 inch D.A. |
| 32 | to | 355 | Hz @ 16 g peak |
| 355 | to | 525 | Hz @ .0025 inch D.A. |
| 525 | to | 2000 | Hz @ 35 g peak |

RANDOM DWELL CRITERIA

Random Levels

| | | | |
|---|---|---|---|
| 20 | to | 250 | Hz @ 0.1 $(grms)^2/Hz$ |
| 250 | to | 480 | Hz @ +9 db/octave |
| 480 | to | 680 | Hz @ 0.7 $(grms)^2/Hz$ |
| 680 | to | 795 | Hz @ -24 db/octave |
| 795 | to | 960 | Hz @ 0.2 $(grms)^2/Hz$ |
| 960 | to | 1100 | Hz @ +9 db/octave |
| 1100 | to | 1400 | Hz @ 0.3 $(grms)^2/Hz$ |
| 1400 | to | 1500 | Hz @ -18 db/octave |
| 1500 | to | 2000 | Hz @ 0.2 $(grms)^2/Hz$ |

Sinusoids

| | | |
|---|---|---|
| 105 | Hz @ | 5 g peak |
| 570 | Hz @ | 15 g peak |
| 1140 | Hz @ | 15 g peak |
| 1710 | Hz @ | 12 g peak |

Total Composite Level = 29.6 grms

ENVIRONMENTAL AREA NO. 7 - Turbopump Housing

SINUSOIDAL SWEEP CRITERIA

| | | | |
|---|---|---|---|
| 5 | to | 23 | Hz @ 0.3 inch D.A. |
| 23 | to | 490 | Hz @ 8 g peak |
| 490 | to | 1025 | Hz @ 0.00065 inch D.A. |
| 1025 | to | 2000 | Hz @ 35 g peak |

RANDOM DWELL CRITERIA

Random Levels

| | | | |
|---|---|---|---|
| 20 | to | 1200 | Hz @ 0.15 $(grms)^2/Hz$ |
| 1200 | to | 1330 | Hz @ 21 db/octave |
| 1330 | to | 2000 | Hz @ 0.3 $(grms)^2/Hz$ |

Sinusoids

570 Hz @ 10 g peak
1140 Hz @ 20 g peak
1710 Hz @ 10 g peak
Total Composite Level = 26.6 grms

ENVIRONMENTAL AREA NO. 8 - Composite Environment

SINUSOIDAL SWEEP CRITERIA

5 to 36 Hz @ 0.3 inch D.A.
36 to 315 Hz @ 20 g peak
315 to 495 Hz @ 0.004 inch D.A.
495 to 1105 Hz @ 50 g peak
1105 to 1210 Hz @ 0.0008 inch D.A.
1210 to 2000 Hz @ 60 g peak

RANDOM DWELL CRITERIA
Random Levels

20 to 395 Hz @ 0.3 $(grms)^2/Hz$
395 to 500 Hz @ +9 db/octave
500 to 1200 Hz @ 0.6 $(grms)^2/Hz$
1200 to 1310 Hz @ +30 db/octave
1310 to 1590 Hz @ 1.4 $(grms)^2/Hz$
1590 to 1800 Hz @ -21 db/octave
1800 to 2000 Hz @ 0.6 $(grms)^2/Hz$

Sinusoids
570 Hz @ 40 g peak
1140 Hz @ 40 g peak
Total Composite Level = 54.7 grms

ENVIRONMENTAL AREA NO. 9 - Oxidizer Dome

SINUSOIDAL SWEEP CRITERIA

5 to 23 Hz @ 0.3 inch D.A.
23 to 100 Hz @ 8 g peak
100 to 200 Hz @ 0.015 inch D.A.
200 to 2000 Hz @ 30 g peak

RANDOM DWELL CRITERIA
Random Levels

20 to 400 Hz @ 0.1 $(grms)^2/Hz$
400 to 450 Hz @ +36 db/octave
450 to 600 Hz @ 0.4 $(grms)^2/Hz$
600 to 730 Hz @ -15 db/octave
730 to 2000 Hz @ 0.15 $(grms)^2/Hz$

Sinusoid
1140 Hz @ 10 g peak
Total Composite Level = 19.5 grms

ENVIRONMENTAL AREA NO. 10 - Interface Panel

SINUSOIDAL SWEEP CRITERIA

5 to 23 Hz @ 0.3 inch D.A.
23 to 490 Hz @ 8 g peak
490 to 950 Hz @ 0.00065 inch D.A.
950 to 2000 Hz @ 30 g peak

RANDOM DWELL CRITERIA
Random Levels

20 to 2000 Hz @ 0.15 $(grms)^2/Hz$

Sinusoids
100 Hz @ 5 g peak
570 Hz @ 10 g peak
1140 Hz @ 10 g peak
1710 Hz @ 10 g peak
Total Composite Level = 21.4 grms

The sinusoidal sweep criteria of the preceding ten environmental areas are used to describe the transient vibration excitation environment. The random dwell criteria are representative of the anticipated engine generated mainstage vibration environment. For sinusoidal vibrations superimposed during the random dwell criteria, the frequency components at 570 Hz, 1140 Hz, and 1710 Hz are representative of integral multiples of turbopump speed at the nominal engine operating point. However, to assure integrity under vibratory loading during throttling operations from 1800K to 1350K all components must be designed to withstand the sinusoidal vibration amplitudes specified for the nominal frequencies of 570 Hz, 1140 Hz, and 1710 Hz for frequency ranges of 470 to 600 Hz, 940 to 1200 Hz, and 1410 to 1800 Hz, respectively.

SINUSOIDAL SWEEP CYCLE CRITERIA - The sinusoidal sweep cycle, for each of the three major axes at the frequencies and levels specified for each environment, shall be logarithmic from 5 Hz to 2000 Hz and back to 5 Hz. The total time per cycle shall

be 10 minutes. Allowable tolerances applicable when testing (Except below 20 Hz where machine tolerances will be used) shall be:

Amplitude ±10%

Frequency ±5%

Time +10%/-0%

RANDOM DWELL CRITERIA - A 15-minute exposure for the random dwell criteria is required for each of the three major axes at the frequencies and levels specified in each environment. The random level in the flat portions of the spectrum shall not deviate by more than +3db,-1db using the analyzer bandwidth of 50 Hz. The rolloff characteristics below 20 Hz and above 2000 Hz shall be 12 db per octave minimum. In addition to the random levels, sinusoids shall be superimposed at the frequencies and levels specified for each environment for the full 15 minute duration. The specified level is the summation of the random and sinusoidal energy. Allowable tolerances applicable when testing shall be:

Sinusoidal Amplitude ±10%

Sinusoidal Frequency ±5%

Time +10%/-0%

Total Composite Level ±10%

Components and the vibrational environment for which the component is to be designed are listed in the following table.

| COMPONENT NAME | VIBRATION ENVIRONMENTAL AREA NUMBER |
|---|---|
| **Engine Control and Monitoring System** | |
| Engine Arming Unit | 1 |
| Engine Control Unit | 1 |
| Engine Monitoring Unit | 1 |
| Ignition Control Unit | 1 |
| Sequence Instrumentation Unit | 1 |
| Engine Pressure Switches | 1 |
| Engine Hydraulic Supply Line | 1 |
| Engine Hydraulic Return Line | 1 |
| Main Oxidizer Valve Open, Close and Sequence | |

| | |
|---|---|
| Line (T/C End) | 1 |
| Main Oxidizer Valve Open, Close and Sequence Line (Valve End) | 6 |
| Ground Hydraulic Supply Line (T/C End) | 1 |
| Ground Hydraulic Supply Line (Interface End) | 10 |
| Ground Hydraulic Return Line (T/C End) | 1 |
| Ground Hydraulic Return Line (Interface End) | 10 |
| Gas Generator Hydraulic Open Line (T/C End) | 1 |
| Gas Generator Hydraulic Open Line (GG Valve End) | 4 |
| Gas Generator Hydraulic Close Line (T/C End) | 1 |
| Gas Generator Hydraulic Close Line (GG Valve End) | 4 |
| Gas Generator Redundant Close Hydraulic Supply Line (T/C End) | 1 |
| Gas Generator Redundant Close Hydraulic Line (GG Valve End) | 4 |

Propellant Valves

| | |
|---|---|
| Oxidizer Throttle Valve | 3 |
| Gas Generator Control Valve | 4 |
| Main Fuel Valve | 5 |
| Main Oxidizer Valve | 6 |

Flight Instrumentation

| | |
|---|---|
| Pump Speed - Magnetic Pickup | 7 |
| Pressure Transducer DC to DC Type | 8 |

Miscellaneous

| | |
|---|---|
| Coupling Assembly - Flight Half (Quick Disconnects) | 8 |
| Gimbal Assembly | 9 |
| Engine Harnesses | 8 |

Interconnect Lines and Ducting

| | |
|---|---|
| Oxidizer Ducts #1 and #2 (Valve End) | 6 |
| Oxidizer Ducts #1 and #2 (T/P Outlet Flange) | 3 |
| Fuel Ducts #1 and #2 (Valve End) | 5 |
| Fuel Ducts #1 and #2 (T/P Outlet Flange) | 2 |
| Gas Generator Fuel Bootstrap Line (GG End) | 4 |
| Gas Generator Fuel Bootstrap Line (Scoop End) | 2 |
| Gas Generator Oxidizer Bootstrap Line (GG End) | 4 |

Gas Generator Oxidizer Bootstrap Line (Throttle Valve End) 3

c. GIMBALING LOADS - The engine shall be designed to withstand combined loads resulting in accordance with paragraph 3.1.1.1.6, Gimbaling Properties; paragraph 3.1.2.4.6.a. Performance Level Loads; paragraph 3.1.2.4.6 b. Vibration Loads; paragraph 3.1.2.4.6 d., Flight Acceleration Loads; and net aerodynamic forces in accordance with paragraph 3.1.2.4.6 e., Flight Aerodynamic Loads, which result in a maximum load not exceeding the thrust chamber actuator attach point load transmitting capability in accordance with paragraph 3.2.1.2.4.1 or 3.2.1.2.4.2, Actuator Connect Points.

d. FLIGHT ACCELERATION LOADS - The engine shall be designed to withstand any combination of lateral loading up to 0.5 g's and longitudinal loading up to 5.5 g's resulting from vehicle accelerations, providing that engine angular displacement is limited with respect to longitudinal acceleration as indicated in Diagram A.

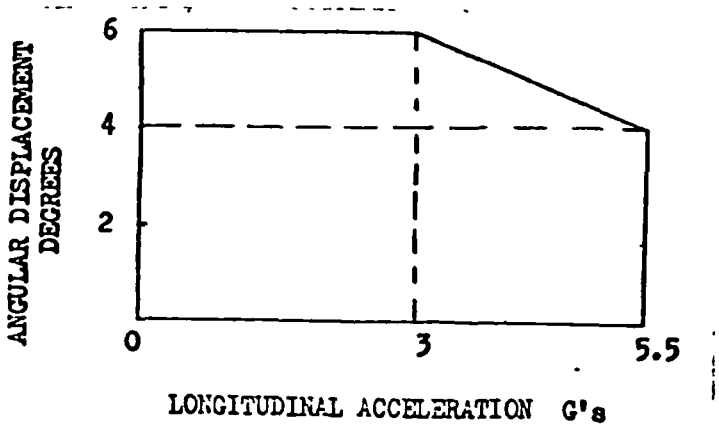


DIAGRAM A

e. FLIGHT AERODYNAMIC LOADS - The engine shall be designed to withstand net aerodynamic loads in combination with gimbal loads in accordance with paragraph 3.1.7.4.6 c., Gimbaling Loads. In addition, the engine shall be designed to withstand a maximum localized dynamic pressure loading of 1.2 psi.

f. LAUNCHER/VEHICLE RELEASE LOADS - The engine system shall be designed to withstand the longitudinal and lateral acceleration loading resulting from an uncontrolled vehicle release rate from the launcher. These loads are specified in Figure (TBD).

3.1.2.5 TRANSPORTABILITY - The engine shall be designed to comply with the provisions of R-3896-9, F-1 Rocket Engine Transportation Manual using the Ground Support Equipment complying with paragraph 3.1.2.2 Maintainability.

3.1.2.5.1 HANDLING AND SHIPPING LOADS - The engine shall be designed to withstand an acceleration of 4g's in any direction during handling and shipping.

3.1.2.5.2 HANDLING AND SHIPPING ENVIRONMENT - The engine shall be designed to be capable of transportation on the earth when exposed to an ambient temperature range of minus 30F to plus 140F at a relative humidity of 95 percent without degradation of reliability or operating life.

3.1.2.5.3 HANDLING AND SHIPPING ATTITUDE - The engine shall be designed not to suffer any detrimental effects during handling and shipping where the engine attitude is maintained at no more than 7 degrees from the horizontal (forward end down); exceptions to this requirement shall be specified in this paragraph and be repairable by specified maintenance procedures.

3.1.2.5.4 HANDLING AND SHIPPING PREPARATION - The engine shall be prepared for handling and shipping in accordance with paragraph 3.3.1.1 Drawings.

3.1.2.5.4.1 OPERATION CONTROL SYSTEM - The operational control system shall be designed to be shipped with the fluid passages either completely or partially filled with hydraulic fluid in accordance with paragraph 3.2.1.2.1.5 Hydraulic Control Fluid.

3.1.2.6 HUMAN PERFORMANCE - To be determined.

3.1.2.7 SAFETY - The engine system shall be designed to comply with the following safety provisions.

3.1.2.7.1 PERSONNEL SAFETY - Personnel safety shall consider all engine operations that are hazardous to personnel. The requirements under paragraph 3.1.2.7.2, Equipment Safety, also apply. Personnel safety shall be maintained by design, procedure or specification when any personnel are involved during engine servicing, checkout or operation.

3.1.2.7.1.1 CLOSURE VENTING - Closures on the engine shall not be capable of maintaining a differential pressure greater than TBD psi.

3.1.2.7.1.2 SAFE OPERATING PRESSURE (FLIGHT HARDWARE) - Safe operating pressure is defined as the maximum operating pressure (including surges) permitted without special protection for personnel. The engine system shall be designed to meet the following conditions for establishing the safe operating pressure.

1. All pressure vessels, components and systems containing poisonous, corrosive or flammable fluids (flash point of 80F or less), or other fluids at temperatures above their boiling points at atmospheric pressure (cryogenics and gases) shall be designed for a burst pressure equal to or greater than 4.0 times the safe operating pressure and have been proof pressure tested to at least 1.5 times the safe operating pressure.

2. All pressure vessels, components and systems containing liquids other than those specified in Item (1.) shall be designed for a burst pressure equal to or greater than 2.5 times the safe operating pressure and have been proof pressure tested to 1.5 times the safe operating pressure. One of each of all components of a system to be pressurized, with personnel present, in excess of one-fourth of the calculated or specified minimum burst pressure must have passed a design verification burst test.

3. All engine systems shall be proof pressure tested to 1.5 times the safe operating pressure. Minor component such as seals and threaded fasteners are replaceable without violating the proof test.

4. Structural design criteria with the associated safety factors and verification testing is specified in Section 3.3 Design and Construction.

5. Safe operating pressures for the individual systems are specified in paragraph 3.1.1.2 Secondary Performance Characteristics.

6. All pressurizing systems used when personnel have access to the engine shall have relief functions adjusted for the safe operating pressure and capable of relieving full source flow under source malfunction conditions.

3.1.2.7.1.3 SAFE OPERATING PRESSURE (GROUND SUPPORT EQUIPMENT) - The safe operating pressure for ground support equipment shall be as specified in the general requirements of Section 3.3 Design and Construction.

3.1.2.7.1.4 LIVE HYPERGOL REMOVAL - The engine shall be capable of having the hypergol expended in the event of engine sequence or hypergol cartridge malfunction.

3.1.2.7.2 EQUIPMENT SAFETY - Equipment safety shall consider all engine operations including but not limited to Storage, Leak and Functional Testing, Pre-Operation Preparation, Operational Use, and Post-Operation Securing.

3.1.2.7.2.1 FAIL-SAFE OPEN - During engine operation, all valves shall remain in the open position in the event of control system opening control pressure loss until propellant flow forces are reduced significantly indicating engine shutdown or closing pressure is applied.

3.1.2.7.2.2 REDUNDANT SHUTDOWN - A redundant method of engine shutdown shall be provided. This method shall include as a minimum separate electrical interfaces, electrical wiring, solenoids, hydraulic control valving, hydraulic lines to the gas generator actuator and engine hydraulic supply, and gas generator valve actuators.

3.1.2.7.2.3 COMBUSTION CHAMBER PURGE - The engine shall be designed to start and shutdown safely without a gaseous nitrogen purge being supplied to the engine combustion chamber or to the gas generator combustion chamber.

3.1.2.7.2.4 IGNITION PROOF - Electrical components other than igniters shall not ignite any explosive mixture surrounding the equipment. Reference paragraph 4.13.4, Explosion Proof (Aeronautical) Test, Procedure III in MIL-E-5272C; Environmental Testing, Aeronautical and Associated Equipment, General Specification for, except as modified by paragraph 5.4.4 Explosion Proof-Aeronautical Equipment.

3.1.2.7.2.5 DYNAMIC STABILITY - The engine shall be designed so that it is dynamically stable[1] with a maximum allowable damping time[1] of TBD milliseconds.

3.1.2.7.2.6 FLUID DRAINS - The engine design shall provide for draining fluids overboard during operation without introducing fire or explosive hazards to the engine or stage.

3.1.2.7.2.7 FLUID LEAKAGE - The engine shall be designed to prevent non-controlled fluid leakage where such leakage could adversely affect the engine, stage or personnel. Allowable leakage rates shall be in accordance with the drawings and specifications for the assembled engine per paragraph 3.3.1.1 Drawings.

3.1.2.7.2.8 RADIO INTERFERENCE GENERATION - Electrical components shall not cause radio interference as defined in MIL-I-6181D, Interference Control Requirements, Aircraft Equipment, except as otherwise approved by the Procuring Activity.

3.1.2.7.2.9 RADIO INTERFERENCE SUSCEPTIBILITY - Electrical controls shall meet the susceptibility requirements established in MIL-I-6181D Interference Control Requirements, Aircraft Equipment. Susceptibility for control components is defined as a change in electrical state which results in an inadvertent operation. These susceptibility requirements shall not apply to instrumentation components and subsystems which do not contain signal conditioning circuitry.

3.1.2.7.2.10 MALFUNCTION - The engine shall be designed to either start, operate or shutdown safely; or to shutdown presenting a minimum hazardous condition and minimum damage to the engine, under specified single conditions of simulated engine malfunction during either transient or stabilized operation.

3.1.2.7.2.11 MAXIMUM OPERATING LEVEL - The engine shall be designed to operate until shutdown by facility or stage specific redline sensing devices at parameter values exceeding maximum rated operating levels.

3.1.2.7.2.12 OPERATING DURATION - The engine shall be designed to be capable of operating for the requirements of paragraph 3.1.2.3 Useful Life when operated within the performance limits in accordance with paragraph 3.1.1.1 Primary Performance Characteristics.

3.1.2.7.2.13 OPERATIONAL INTERLOCKS - The operational control system shall provide interlocks as described in paragraph 3.1.1.2.5 Operational Control System to verify and provide indication to the engine interface that the engine is 1) ready for checkout (one pressure switch activated) or operation (two pressure switches activated), 2) Starting Sequence Complete (allow output of Launch Commit signal), and 3) attainment of a thrust level of TBD percent of rated thrust (to be used for Launch Commit in conjunction with Starting Sequence Complete).

3.1.2.7.2.14 PROPELLANT VAIVE LEAKAGE - Propellant valves shall provide a positive seal against stage tank head pressure with propellants admitted to the engine and without hydraulic pressure supplied to the valves.

3.1.2.7.2.15 PROPELLANT DRAINING - Cavities downstream of propellant valves shall be free draining to prevent accumulation and possible mixing of propellants when the engine attitude is in accordance with paragraph 3.1.1.1.3.1 Starting Attitude.

3.1.2.7.2.16 HYDRAULIC SYSTEM RETURN FLUID FLOW - The hydraulic system return fluid control valve shall be sequenced to minimize the amount of ground hydraulic fluid (RJ-1), allowed to mix with the fuel (RP-1) during engine start. The valve shall not redirect the hydraulic fluid flow from the engine to the ground return during engine shutdown until all propellant valves are closed, and should allow bleed off of hydraulic pressure in the ground system during flight.

3.1.2.7.2.17 LOWERED PREFILL - Not applicable

3.1.2.7.2.18 PROTECTIVE CLOSURES - Protective covers or closures shall be designed to preclude the possibility of the component being attached to another component during engine assembly with the cover or closure installed.

TABLE 1

COMPONENT LEAK TEST REQUIREMENTS

| SYSTEM | COMPONENTS | TEST FLUIDS | TEST PRESSURES | NOTES |
|---|---|---|---|---|
| Hydraulic | MF Valve<br>ML Valve<br>GG Valve<br>Engine Control Unit<br>Ignition Control Unit<br>Engine Arming Unit | RP-1, RJ-1, or Hydraulic Oil | 5, 400, 1500, and 3000 | |
| Turbine Drive and Exhaust | GG Combustor, Heat Exchanger<br>Exhaust Manifold | $GN_2$ or Missile Air | 10 | |
| Thrust | Thrust Chamber Assy. | $GN_2$ or Missile Air | 30 | |
| Fuel | MF & GG Valves | $GN_2$ or Missile Air | 5 | No hydraulic pressure. |
| | MF Valve | $GN_2$ or Missile Air | 30 | Reverse leak test-no hydraulic pressure. |
| | MF & GG Valves | RP-1, RJ-1, Hydraulic Oil, $GN_2$ or Missile Air | 15, 30, & 150 | No hydraulic pressure. |
| | MF Valve | RP-1, RJ-1, Hydraulic Oil, $GN_2$ or Missile Air | 15, 30, 150, & 600 | Closing hydraulic pressure of 1200 psig. |
| | MF Valve | RP-1, RJ-1, Hydraulic Oil, $GN_2$ or Missile Air | 2300 | Opening hydraulic pressure of 1200 psig. |
| | GG Valve | RP-1, RJ-1, Hydraulic Oil, $GN_2$ or Missile Air | 15, 30, 150, & 3000 | Closing hydraulic pressure of 1200 psig. |
| | GG Valve | RP-1, RJ-1, Hydraulic Oil, $GN_2$ or Missile Air | 2000 | Opening hydraulic pressure of 1200 psig. |



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TABLE M-1

COMPONENT LEAK TEST REQUIREMENTS

| SYSTEM | COMPONENTS | TEST FLUIDS | TEST PRESSURES | NOTES |
|---|---|---|---|---|
| Oxidizer | ML & GG Valves | $GN_2$ or Missile Air | 5 | No hydraulic pressure. |
| | ML Valve | $GN_2$ or Missile Air | 30 | Reverse leak test - no hydraulic pressure. |
| | ML & GG Valves | LOX or $LN_2$ | 50 & 150 | Closing hydraulic pressure of 400 psig. |
| | ML Valve | LOX or $LN_2$ | 50, 150 & 2100 | Closing hydraulic pressure of 1200 psig. |
| | ML Valve | LOX or $LN_2$ | 2100 | Opening hydraulic pressure of 1200 psig. |
| | GG Valve | LOX or $LN_2$ | 50, 150 & 3000 | Closing hydraulic pressure of 1200 psig. |
| | GG Valve | LOX or $LN_2$ | 2000 | Opening hydraulic pressure of 1200 psig. |



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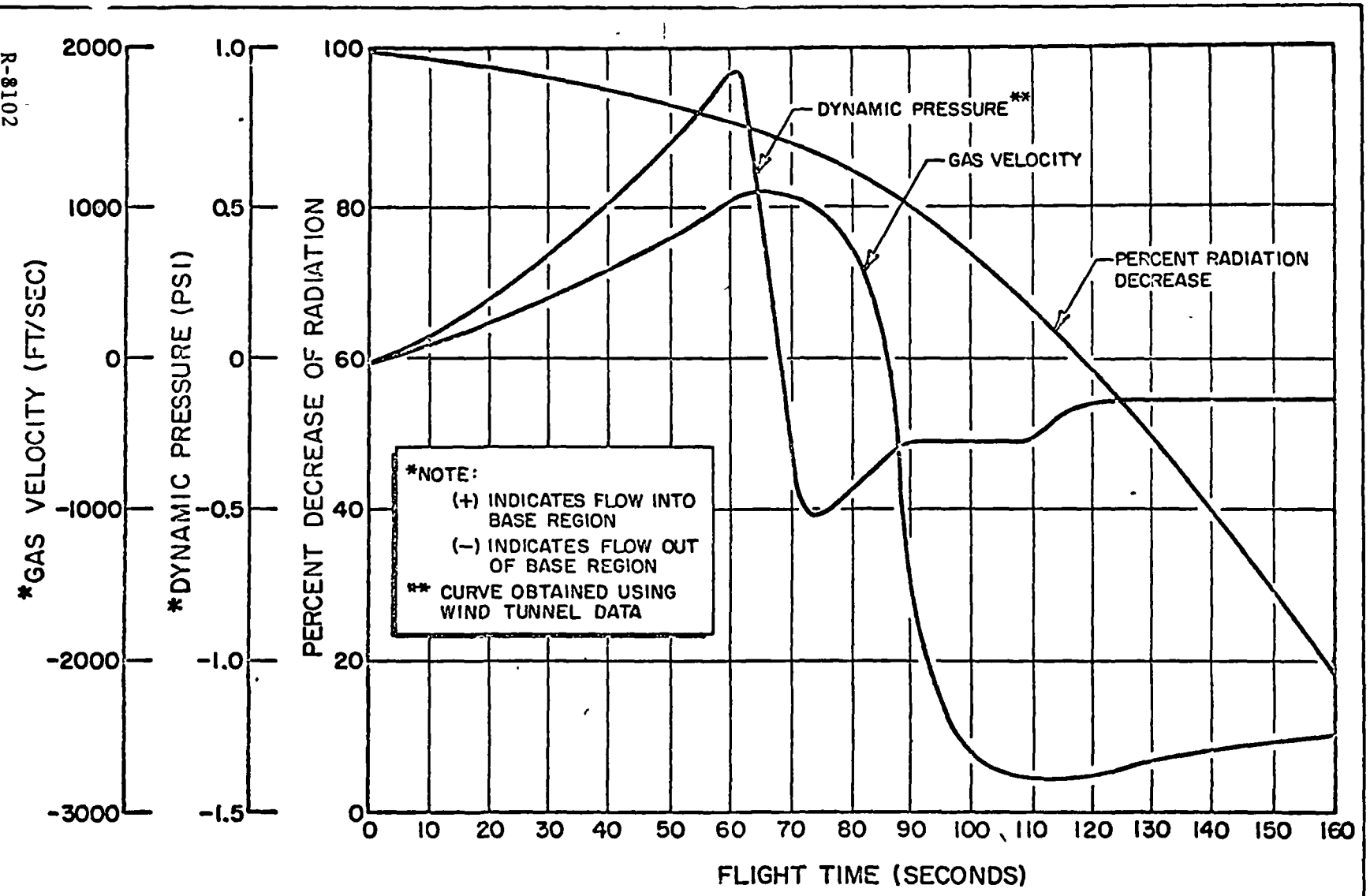
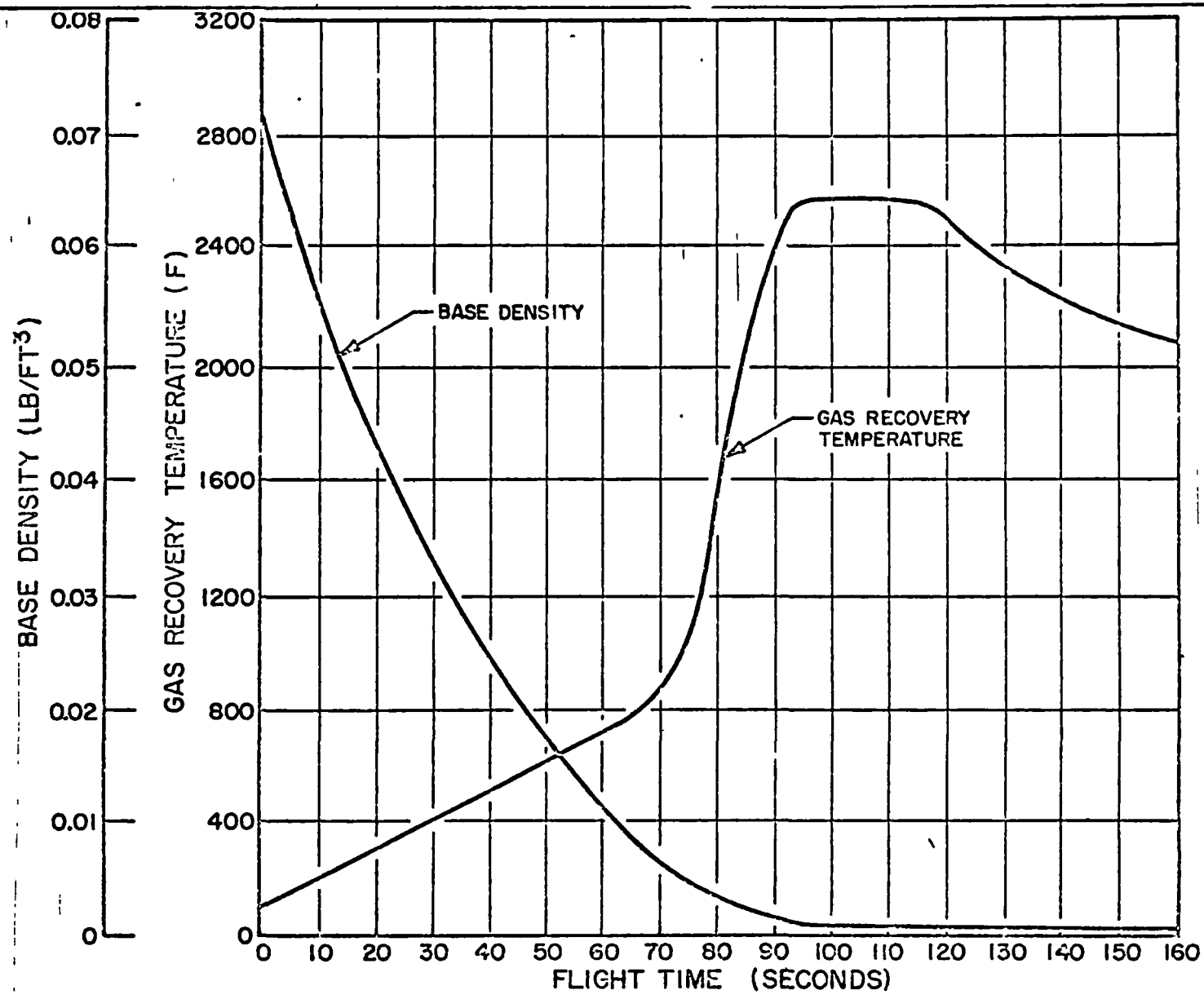



BASE REGION GAS VELOCITY, ESTIMATED BASE REGION DYNAMIC PRESSURE, AND PERCENT DECREASE OF RADIATION vs FLIGHT TIME

Figure N-1

FORM 131-H-2 REV 9-66




ESTIMATED DENSITY IN BASE REGION AND GAS RECOVERY TEMPERATURE vs FLIGHT TIME

Figure N-2

R-8102

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3.2 ENGINE DEFINITION

3.2.1 INTERFACE REQUIREMENTS

3.2.1.1 SCHEMATIC ARRANGEMENT - The engine system is shown schematically in drawing number 101352.

3.2.1.2 DETAILED INTERFACE DEFINITION

3.2.1.2.1 FLUID INPUTS - The engine shall be supplied fluids as follows:

3.2.1.2.1.1 NITROGEN - Nitrogen in accordance with Specification MIL-P-27401B; Propellant Pressurizing Agent, Nitrogen, shall be supplied to the engine for servicing purges. The nitrogen shall be supplied from loading systems equipped with nominal 40 micron or finer filters. These filters shall have a maximum pore size of 100 microns as determined by bubble-point and/or glass-bead testing.

3.2.1.2.1.2 FUEL - The fuel supplied to the engine shall conform to MIL-P-25576C Rocket Fuel, RP-1, and comply with the pre-start and operating conditions as specified in Figure R-1 and the pre-start conditions of Figure R-2 and shall be supplied from a loading system equipped with nominal 70 micron or finer filters. These filters shall have a maximum pore size of 200 microns as determined by bubble-point and/or glass-bead testing.

3.2.1.2.1.3 OXIDIZER - The oxidizer supplied to the engine shall be liquid oxygen conforming to MIL-P-25508C; Propellant, Oxygen; (except as noted below), complying with the pre-start and operating conditions as specified in Figure R-3 and the pre-start conditions of Figure R-2 and shall be supplied from a loading system equipped with nominal 70 micron or finer filters. These filters shall have a maximum pore size of 200 microns as determined by bubble-point and/or glass-bead testing. The acetylene content shall be no larger than 1-1/2 ppm and soluble hydrocarbon content shall not exceed 75 ppm.

3.2.1.2.1.4 HYPERGOL FLUID - Hypergol fluid in accordance with R-6749, F-1 Engine Interface Document, shall be provided for thrust chamber and gas generator ignition.

3.2.1.2.1.5 HYDRAULIC CONTROL FLUID - The hydraulic fluid supplied to the engine from a ground source for engine starting shall conform to MIL-P-25576C; Rocket Fuel, RP-1 or MIL-F-25558B; Fuel, Ramjet Engine, Grade RJ-1. The fuel shall be provided within a temperature range of 35F to 150F and the ground source shall be equipped with nominal 10 micron or finer filters. These filters shall have a maximum pore size of 25 microns as determined by bubble-point and/or glass-bead testing.

3.2.1.2.1.6 THRUST CHAMBER PREFILL FLUID - Not applicable

3.2.1.2.1.7 SERVICING FLUIDS - Engine servicing fluid requirements shall be in accordance with R-3896-3, F-1 Rocket Engine Maintenance and Repair Manual except as specified in this specification.

3.2.1.2.1.8 GIMBAL HYDRAULIC RETURN - The engine shall be capable of accepting gimbal hydraulic return fluid within the flowrate range of zero to 85 gpm and within the pressure range of 0-200 psia through each of the two interfaces.

3.2.1.2.2 FLUID OUTPUTS - The engine shall supply fluids as follows:

3.2.1.2.2.1 GIMBAL HYDRAULIC SUPPLY - The engine shall be capable of supplying fuel at each of the gimbal hydraulic fluid supply interfaces, within the flowrate range of zero to 85 gpm and within the pressure range of 2200 to 2400 psia (total) while the engine is operating within the performance limits and at the standard conditions of paragraph 3.1.1 Functional Characteristics. The available supply pressure at a thrust level of 1350 kips shall be 1300 psia (total). Gimbal hydraulic supply pressure variations resulting from operation at other than these steady state conditions and for start and shutdown transients are provided in Figures G-2, G-5, and G-6.

3.2.1.2.2.2 HYDRAULIC CONTROL FLUID RETURN - Return hydraulic fluid shall flow from the engine in accordance with paragraph 3.1.1.2.5, Operational Control System.

3.2.1.2.3 FLUID INTERFACES

3.2.1.2.3.1 FUEL PUMP INLET NO. 1 - The engine shall interface at the No. 1 fuel pump inlet in accordance with R-6749, F-1 Engine Interface Document. Fuel in accordance with paragraph 3.2.1.2.1.2 Fuel shall flow to the engine through this interface.

3.2.1.2.3.2 FUEL PUMP INLET NO. 2 - The engine shall interface at the No. 2 fuel pump inlet in accordance with R-6749, F-1 Engine Interface Document. Fuel in accordance with paragraph 3.2.1.2.1.2 Fuel shall flow to the engine through this interface.

3.2.1.2.3.3 LOX PUMP INLET - The engine shall interface at the LOX pump inlet in accordance with R-6749, F-1 Engine Interface Document. Oxidizer in accordance with paragraph 3.2.1.2.1.3 Oxidizer shall flow to the engine through this interface.

3.2.1.2.3.4 HYDRAULIC SUPPLY - The engine shall interface at the hydraulic fluid supply line in accordance with (TBD). Hydraulic control fluid in accordance with paragraph 3.2.1.2.1.5

Hydraulic Control Fluid shall flow to the engine through this interface.

3.2.1.2.3.5 HYDRAULIC RETURN - The engine shall interface at the hydraulic fluid return line in accordance with TBD. Return hydraulic control fluid in accordance with paragraph 3.2.1.2.2.2 Hydraulic Control Fluid Return shall flow from the engine through this interface.

3.2.1.2.3.6 LOX DOME & GG LOX INJECTOR PURGE - Not applicable

3.2.1.2.3.7 TURBOPUMP SEAL CAVITY PURGE - Not applicable

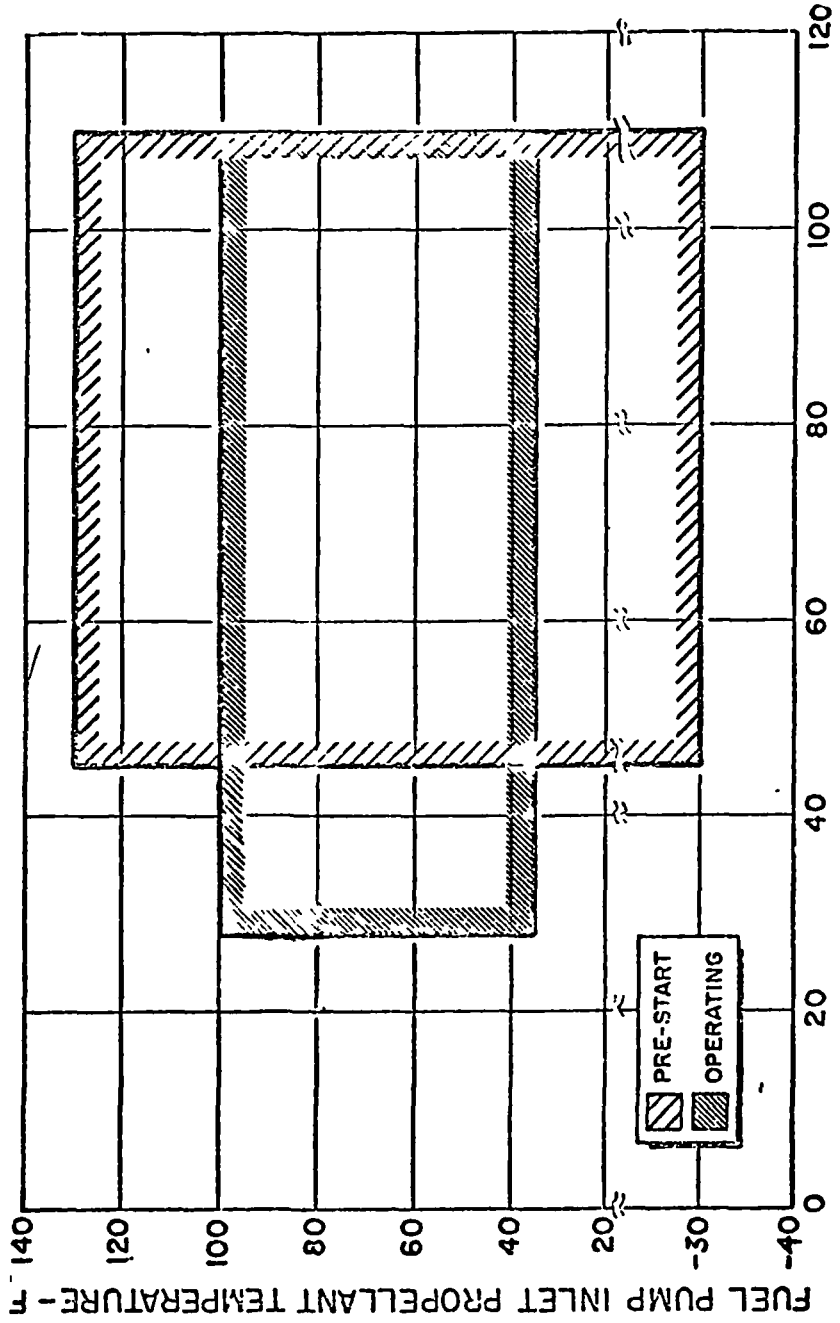
3.2.1.2.3.8 THRUST CHAMBER JACKET PREFILL - Not applicable

3.2.1.2.3.9 GIMBAL SYSTEM SUPPLY NO 1 - The engine shall interface at the No. 1 gimbal actuator supply port in accordance with (TBD). Hydraulic fluid in accordance with paragraph 3.2.1.2.2.1 Gimbal Hydraulic Supply shall flow from the engine through this interface.

3.2.1.2.3.10 GIMBAL SYSTEM RETURN NO. 1 - The engine shall interface at the No. 1 gimbal actuator return port in accordance with (TBD). Hydraulic fluid in accordance with paragraph 3.2.1.2.1.8 Gimbal Hydraulic Return shall flow to the engine through this interface.

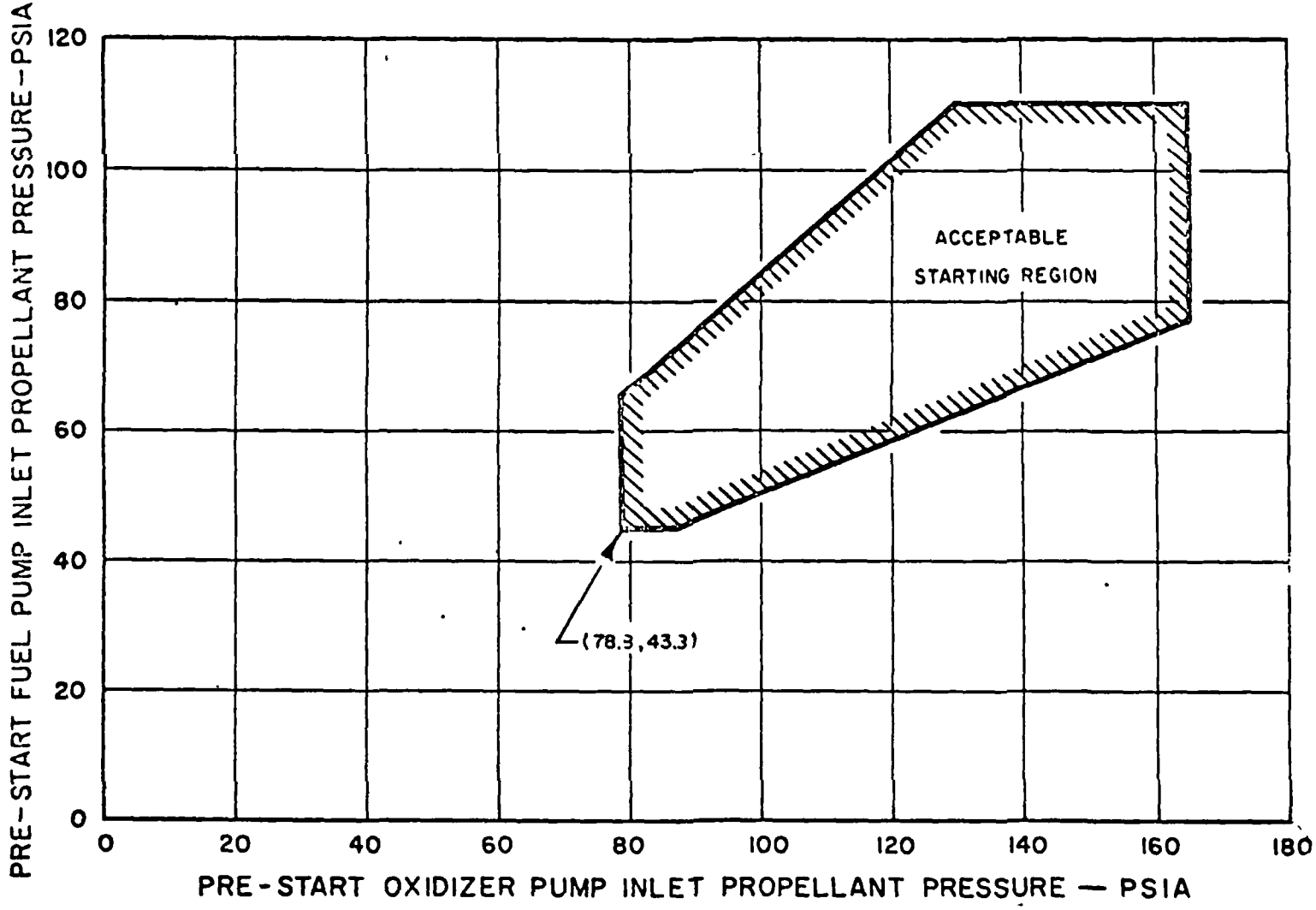
3.2.1.2.3.11 GIMBAL SYSTEM SUPPLY NO. 2. - The engine shall interface at the No. 2 gimbal actuator supply port in accordance with (TBD). Hydraulic fluid in accordance with paragraph 3.2.1.2.2.1 Gimbal Hydraulic Supply shall flow from the engine through this interface.

3.2.1.2.3.12 GIMBAL SYSTEM RETURN NO 2. - The engine shall interface at the No. 2 gimbal actuator return port in accordance with (TBD). Hydraulic fluid in accordance with paragraph 3.2.1.2.1.8 Gimbal Hydraulic Return shall flow to the engine through this interface.



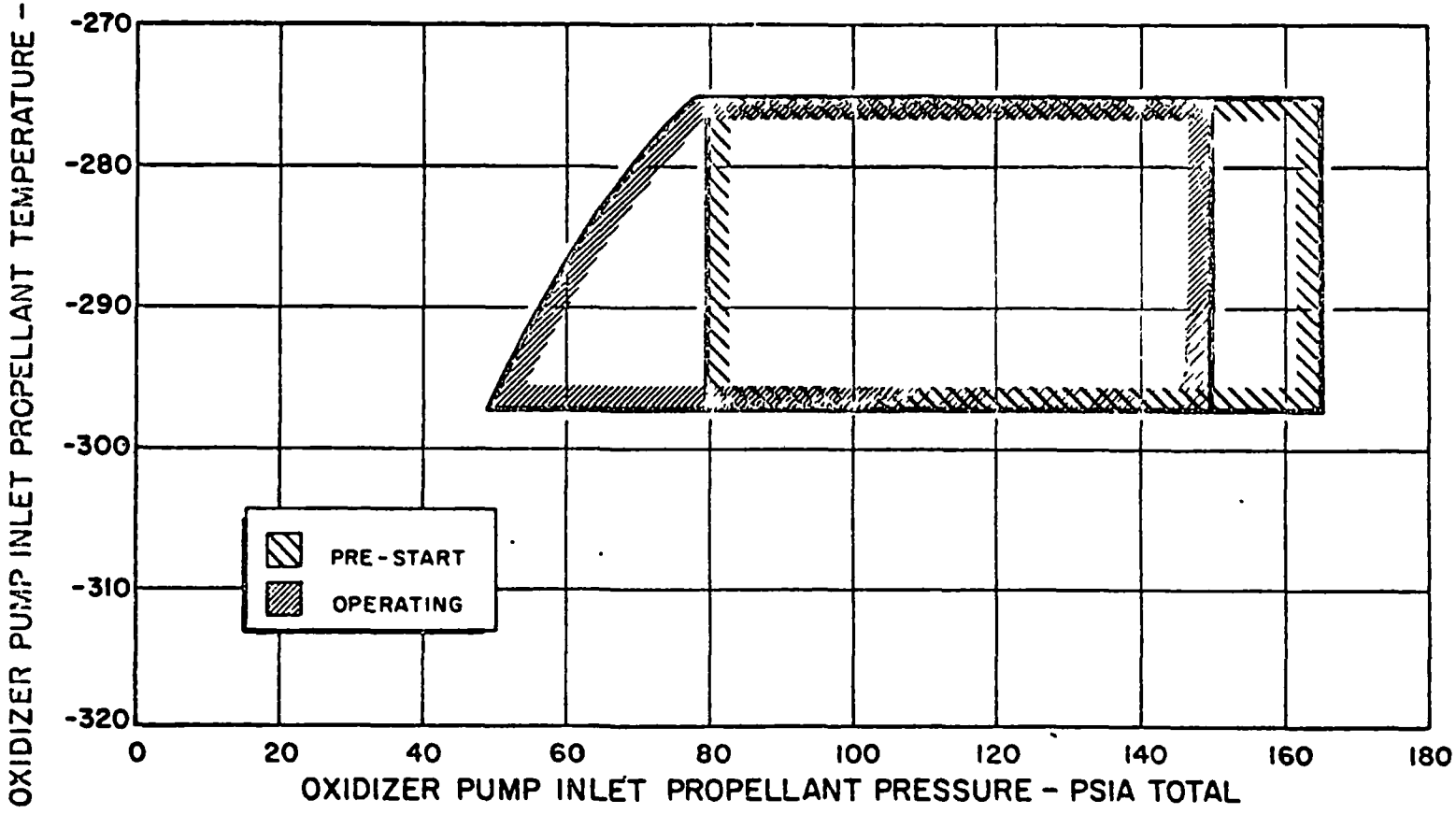

FUEL PUMP INLET PRE-START AND OPERATING PROPELLANT CONDITIONS

Figure R-1




OXIDIZER VS FUEL PUMP INLET PROPELLANT PRESSURES
ACCEPTABLE FOR STARTING THE F-1A ENGINE

Figure R-2




OXIDIZER PUMP INLET PRE-START AND OPERATING PROPELLANT CONDITIONS

Figure R-3

3.2.1.2.4 MECHANICAL INTERFACES

3.2.1.2.4.1 GIMBAL ACTUATOR MOUNT NO. 1 - The engine shall be attached at the No. 1 gimbal actuator mount in accordance with R-6749, F-1 Engine Interface Document.

3.2.1.2.4.2 GIMBAL ACTUATOR MOUNT NO 2. - The engine shall be attached at the No. 2 gimbal actuator mount in accordance with R-6749, F-1 Engine Interface Document.

3.2.1.2.4.3 GIMBAL BEARING - The engine shall be attached at the gimbal bearing in accordance with R-6749 F-1 Engine Interface Document.

3.2.1.2.4.4 INTERFACE PANEL - The engine shall be attached at the interface panel in accordance with (TBD).

3.2.1.2.5 ELECTRICAL INPUTS - Electrical power inputs shall be consistent with specification TBD.

3.2.1.2.5.1 ENGINE CONTROL - (TBD)

3.2.1.2.5.2 FLIGHT INSTRUMENTATION - (TBD)

3.2.1.2.5.3 THRUST CONTROL - (TBD)

3.2.1.2.6 ELECTRICAL OUTPUTS - (TBD)

3.2.1.2.6.1 ENGINE CONTROL - (TBD)

3.2.1.2.6.2 FLIGHT INSTRUMENTATION - (TBD)

3.2.1.2.6.3 THRUST CONTROL - (TBD)

3.2.1.2.7 ELECTRICAL INTERFACES - (TBD)

3.2.1.2.8 SERVICING INTERFACES - (TBD)

3.2.2 COMPONENT IDENTIFICATION

3.2.2.1 GOVERNMENT FURNISHED PROPERTY LIST - (TBD)

3.2.2.2 ENGINEERING CRITICAL COMPONENTS LIST - The Engineering Critical Component List shall include but not be limited to the following.

a. Turbopump

b. Gas generator valve

c. Gas generator assembly (injector and combustor)

d. Main LOX valve

e. Main fuel valve

f. Engine Control Unit

g. Engine Arming Unit

h. Ignition Control Unit

i. Engine Monitor Unit

j. Sequence Instrumentation Unit

k. Pressure Switches

3.2.2.3 LOGISTICS CRITICAL COMPONENTS LIST - Not applicable

3.3 DESIGN AND CONSTRUCTION - Design criteria and recommended practices for the guidance of design shall be as set forth in Rocketdyne Design Manual and as follows.

3.3.1 GENERAL DESIGN FEATURES - The general design features of the engine shall include the considerations necessary to provide the requirements of paragraph 3.1 Performance and paragraph 3.2 Engine Definition and will include the following.

3.3.1.1 DRAWINGS - Engineering drawings for the engine, accessories and detail components shall be in accordance with the following:

| | |
|---|---|
| 101351-X | Pocket Engine Assembly |
| 306326-X | Gas Generator System Installation |
| 308951-X | Pressurization System Installation |
| 411126-X | Propellant Feed System Installation |
| 501376-X | Electrical System Installation |
| 600851-X | Hydraulic Control System Installation |
| 704752-X | Instrumentation System Installation |
| TBD | Loose Equipment Installation |
| TBD | Marking Identification Installation |
| TBD | Insulation Assembly |
| TBD | Insulation Installation |

3.3.1.2 RATING CAPABILITY COMPONENT REPLACEMENT - The engine system shall be designed to allow specified components to be replaced with redesigned units that will allow operation at rating extremes.

3.3.1.2.1 REPLACEABLE COMPONENTS LIST - (TBD)

3.3.1.3 SUB-SYSTEM DESIGN FEATURES - The engine system shall be designed to provide the following features for sub-systems.

3.3.1.3.1 OVERALL SUB-SYSTEMS - The following design requirements shall be applicable to all sub-systems.

1. All engine components shall be designed to be non-interchangeable, or to allow installation in more than one functional position except where

parts are physically and functionally the same in each application or if more than one component is utilized in the engine.

2. All orifice plates shall be designed not to be interchangeable, or installed in a manner that precludes repeatable orifice performance. In addition orifice diameter tolerance, edge control, and/or fluid resistance variation limits shall be established. Installation and identification of all variable orifices used in all systems, subsystems and components including size, dimensions, edge control, tolerance, resistance, and part number shall be capable of verification after installation of these variable orifices in all systems, subsystems and components. This verification of installation and identification shall be accomplished without removal of components, lines, fittings, assemblies, nuts, bolts, integral installations, and/or any other disassembly of the engine assembly.

3. The engine system shall be designed to be capable of the most stringent of the requirements for operation, checkout or qualification. In all cases the requirements of paragraph 3.1.2.7.1.2 Safe Operating Pressure shall apply.

4. The engine system shall be designed to utilize as far as possible the following design features for Flange Joint Design. No threaded or flared tubing ("B" nut) type connection shall be used.

   a. Minimum bolt circle diameter

   b. Utilize standard strength/type/lubrication bolts

   c. Utilize through bolt holes

   d. Utilize identical bolt diameters and lengths for adjacent flanges

   e. Utilize standard washers that do not require uni-directional installation

   f. Utilize standard strength/type/lubrication nuts

g. Utilize Keensert non-locking, silver plated internal, cadmium plated external inserts if through holes are not possible.

h. Utilize either Gask-O-Seals or Naflex seals for all joints. Exposure of seals to hypergol fluids shall be minimized. Seal joints exposed to hypergol fluid shall be designed to be washed free of hypergol with igniter fuel flow during engine operation. In the event that seals are exposed to hypergol fluid which cannot be removed by the washing effect of fuel, the seals shall be designed to preclude detrimental effects arising from such exposure and shall have a useful life equivalent to the engine useful life.

i. Incorporate leak monitoring capability on Naflex installations that do not have a comparative joint history.

j. Seal-joint tolerance stack-ups layouts shall be utilized.

5. No cored passages shall be used where either the coring material or the casting material can generate or become contamination sources. All drilled or bored passages shall be deburred.

6. Pins or similar type components used as hinges shall be self retained.

7. Weight of all component and subsystems shall be held to a minimum, consistent with the use of high strength to weight ratio materials and within the requirements of reliability goals and structural integrity in the environment specified.

8. No components shall be attached to lines where the attaching component torque requirement is greater than the part to which it is attached, such as fittings in instrumentation or quick-disconnects for purging or flushing service attachment. Quick-disconnects shall have a bolt-flange connection to the engine; threaded bosses shall not be used. Instrumentation bosses which are a permanent connection on the engine may provide a threaded female connection for the

ground test line, but shall not permit the use of adapters to increase the ground test line size above the nominal instrument boss line size which would violate torque requirements.

3.3.1.3.2 HYDRAULIC CONTROL SYSTEM INSTALLATION - The hydraulic control system shall be designed with the following features.

1. The Hydraulic Control Lines shall be capable of being installed or replaced without the need for removal of other lines, components, or special tools.

2. There shall be no fittings (tees, instrument bosses, fixed orifices, etc.) in the Hydraulic Control Line assemblies.

3. The Hydraulic Control Lines shall be capable of being installed without the need for reforming or adjustment during installation.

4. Installation of the Hydraulic Control Lines shall permit replacement of any hydraulic control package, or a propellant valve without the need for line removal.

5. The Hydraulic Control Lines shall utilize a multiple-passage one-piece line manifold with bolted flange type end connections for minimum interface envelope wherever possible.

6. The Hydraulic Control Lines shall utilize a replaceable gask-O-Seal seal plate for the bolted flange interfaces.

7. Protective covers shall be provided for and installed on all sealing surfaces when machining is complete.

8. Joints between tubes and fittings shall be of a permanent type, either brazed or welded. Weld joints shall comply with Rocketdyne Specification RA0107-027 for butt-weld joints, or Rocketdyne Specification RA0607-050 for the fillet and fusion weld joint. Brazed joints shall be in accordance with specification TBD. "B"-nuts or other threaded type fittings are not permitted.

9. Routing of lines shall minimize joints, interfaces, or other potential leakpaths.

10. Lines requiring supplemental support on engine installation shall comply with the following:

    LINE SUPPORTS

    Three quarter inch diameter lines and less shall use loop type wire-mesh cushion CRES clamps per RE127-2001-xxxx Rocketdyne Standard as supplied by Adel or Titeflex only.

    Three quarter inch diameter lines and larger shall use a line block type support similar to and consisting of a cap P/N 601934 and a base P/N 601933 containing a wire-mesh cushion pad P/N K2207-xx as supplied by Robintech only.

    Should multiple-passage lines (manifolded) require additional support (other than end connectors) the support shall be of a design similar to that required for individual lines 1" dia. and larger.

11. Line support spacing shall be in accordance with the requirements of MIL-H-25475A.

12. All lines and Hydraulic Control Line assemblies shall be serialized in accordance with RA0104-007, including spares. The serialization shall be traceable to the assembly tool fixture; the fixture having previously received the coordinated approval of engineering, quality control, and manufacturing.

13. Only permanent identification shall be applied to line assemblies. The identification shall be electro chem etched on the part in accordance with RA0104-008.

14. The use of epoxy or similar adhesives shall not be used internal to the hydraulic system.

15. All permanently installed lines on the engine, such as the permanent lines from the hydraulic control package mounting pads to the main fuel valves, shall be capable of potential leak repair.

16. Component interfaces with the hydraulic system shall provide a sealing surface at the interface in only one plane.

17. Orifices required for functional valve timing shall be an integral part of the seal plates where applicable.

18. All weld joints exposed to hydraulic system pressures shall be Class I, which require radiographic inspection. As such, design shall consider weld accessibility for radiographic inspection requirements; Ref: PA0115-006.

19. In the event re-welding per PA0107-027 or RA0607-050 is required, only one additional weld shall be permitted.

20. Only machine type welds per RA0107-027 or RA0607-050 shall be permitted.

21. Lines shall be routed to clear adjacent structure a minimum of 1/4" for static installations and a minimum of 1/2" at the extreme position of dynamic installations. Dynamic is construed to mean that a line changes position with relation to its adjacent structure through thermal, pressure, or other test or operative conditions.

22. Flexible hose or tubing for engine lines installations shall be kept to a minimum.

23. Orifices smaller than .070" diameter shall be protected by a filter element having a screened opening .008 to .012 inch. These filter elements shall be designed such that they are not affected by the high velocity fluid stream from the orifice. All sense ports which receive signal pressures with non-filtered fluid shall also be protected with filters.

24. Components of the hydraulic system which exceed 40 pounds in handling weight shall be equipped with handling lugs.

25. Design shall consider servicing and maintenance of engine components using readily available mechanics tools. Special tools shall be minimized and those required coordinated with D/596-158 engine systems prior to releasing a design.

26. A minimum of #10 size fasteners shall be used for attaching line clamps or supports and not less than 1/4 inch size bolts shall be used for flange type line end connectors or pressure sealing plates of components.

27. Components requiring electrical harness attachment shall consider the position and location of electrical connectors to minimize harness bends or need for angle connectors.

3.3.2 SELECTION OF SPECIFICATIONS AND STANDARDS - When Contractor specifications are used for processes that may affect performance or durability of the engine, such specifications shall be released to the Procuring Activity upon release to the Contractor drawing system. The use of non-governmental specifications shall not constitute waiver of Government inspection.

3.3.3 MATERIAL, PARTS AND PROCESSES

3.3.3.1 MATERIALS - Materials used in the manufacture of the engine and accessories shall be of high quality, suitable for the purpose.

3.3.3.1.1 MATERIAL SPECIFICATIONS - Materials shall conform to the applicable specifications listed below in the order of preference:

a. Specifications listed in the "Dept. of Defense Index of Specifications and Standards" (Part I alphabetical listing, Part II numerical listing).

b. Other government, society, or industry specifications.

c. North American Rockwell Company specifications. When Contractor specifications are used for materials that may affect performance or durability of the engine, such specifications shall be released to the Government upon release to the Contractor drawing system. The use of non-governmental specifications shall not constitute waiver of Government inspection.

3.3.3.1.2 COMPATIBILITY OF MATERIALS - All materials shall be verified to be compatible with all environmental fluids to which they are exposed including: propellants, check-out fluids, and flushing and cleaning materials.

3.3.3.1.2.1 LOX COMPATIBILITY - Any material used in the engine which is subject to exposure to GOX or LOX shall be LOX compatible in accordance with MSFC-SPEC-106B unless otherwise approved by the procuring activity. Engine components subject to the requirements of this paragraph shall be established by future specification change.

3.3.3.1.3 FREE MACHINING ALLOYS - Free machining grades of alloys shall not be used in welded applications or in applications requiring good ductility in the transverse direction.

3.3.3.1.4 CONSUMABLE-ELECTRODE REMELT ALLOYS - Consumable electrode remelt alloys shall be specified for bar, forging, and heavy section plate of austenitic-type materials where improved cleanliness will improve the fabricability of the material and the performance of the component.

3.3.3.2 CRITICAL MATERIAL WEIGHTS

The estimated weights of critical materials are as follows:

| Material | Pounds |
|---|---|
| Chromium | |
| Cobalt | |
| Columbium | |
| Gold | |
| Molybdenum | |
| Nickel | |
| Tungsten | |

3.3.4 STANDARD AND COMMERCIAL PARTS

3.3.4.1 STANDARD PARTS - Standard parts shall be used wherever they are suitable for the purpose, and shall be identified by their standard part numbers. The use of nonstandard parts will be acceptable only when standard parts have been determined to be unsuitable.

3.3.4.2 DESIGN - MS, NAS, or AN design standards shall be used wherever applicable.

3.3.4.3 THREADS - Conventional straight screw threads shall conform to the requirements of Specification MIL-S-7742A Screw Threads, Standard, General Specification for or MIL-S-8879 Screw Threads, Controlled Radius with increased Minor Diameter, General Specification for, as applicable.

3.3.5 MOISTURE AND FUNGUS RESISTANCE - (TBD)

3.3.6 CORROSION OF METAL PARTS - All parts shall be corrosion resistant or suitably protected.

3.3.6.1 BELLOWS - All bellows shall be fabricated of nickel-base alloys in order to obtain better corrosion resistance than can be obtained using corrosion-resistant steels.

3.3.6.2 FITTINGS - Fittings made from corrosion-resistant steels shall be acid descaled in order to prevent superficial surface rusting which occurs when corrosion-resistant steels are not thoroughly cleaned.

3.3.6.3 ROD-END, STATIC BEARINGS - Static bearings shall be fabricated from austenitic, corrosion resistant alloys rather than from martensitic steels which have lower corrosion resistance.

3.3.6.4 INSEPTS - It shall be a goal of this design to develope inserts for aluminum components that provide sufficient strength, lubricity, and will be free of corrosion during the life of the engine.

3.3.6.5 STRESS CORROSION - Components which have high residual tensile stresses in a corrosive environment or which past experience has shown are susceptible to stress corrosion, shall be fabricated from materials known to have good resistance to stress corrosion. Any use of precipitation hardened CRES alloys (PH stainless steels) will require specific Rocketdyne approval of each component.

3.3.7 INTERCHANGEABILITY AND REPLACEABILITY

3.3.7.1 PHYSICAL INTERCHANGEABILITY - All components and subsystems having the same Contractor part number shall be interchangeable with respect to installation, except that matched parts or selective fits will be permitted in accordance with paragraph 3.2 Engine Definition.

3.3.7.2 FUNCTIONAL INTERCHANGEABILITY - The engine shall be designed such that all operational control system subsystems are capable of replacement without requiring a recalibration firing of the engine.

3.3.7.3 INTERCHANGEABILITY - Maintenance, checkout and/or recalibration requirements resulting from engine component or subsystem replacements shall be specified in this paragraph. Changes in manufacturer part number shall be governed by the drawing number requirements of Specification (TBD).

3.3.8 WORKMANSHIP - The workmanship and finish shall be of sufficiently high grade to provide satisfactory operation, reliability and durability consistent with the requirements of this specification.

3.3.8.1 AUTOMATIC WELDING - It shall be an objective of this design to automate the welding process as much as practical.

3.3.8.2 TUBE WELDS - It shall be an objective of this design to develope butt-type welds for joining tubes.

3.3.8.3 QUALITY OF WELD SURFACE - Surface porosity and inclusions shall be acceptable provided the size and frequency of the porosity does not exceed the limitations for internal defects as required by the applicable drawing.

3.3.9 ELECTROMAGNETIC INTERFERENCE - (TBD)

3.3.10 IDENTIFICATION AND MARKING - Equipment, assemblies, and parts shall be marked for identification in accordance with specification MIL-STD-130B Identification Marking of U. S. Military Property.

3.3.10.1 ENGINE IDENTIFICATION PLATE - Identification data shall be applied to the engine identification plate as follows:

Engine, Rocket, Liquid Propellant

Government Model Designation ___*___

Model Specification No. ___*___

Serial No. ___*___

Manufacturer's Part No. ___*___

Contract or Order No. ___*___

Manufacturer's Name or Trade-Mark ___*___

US

*Applicable data to be entered by the Contractor.

3.3.10.2 ENGINE MODIFICATION PLATE - The engine modification number (MD) shall be applied to the engine modification plate.

3.3.10.3 CONNECTIONS - The engine shall be permanently marked to indicate all connections shown on the installation drawing for instrumentation, propellant, and other fluid connections. All fluid lines shall be marked in accordance with Drawing AND10375 Colors - Fluid Line Identification.

3.3.10.4 COMPONENTS - Components shall be clearly marked as follows:

(Nomenclature)

Serial No. ___*___

Manufacturer's Part No. ___*___

Revision or Change Letter ___*___

Manufacturer's Name or Trade-Mark ____*_____

*Applicable data to be entered by the Contractor.

3.3.10.5 SYNTHETIC RUBBER PARTS - Synthetic rubber parts shall be fabricated from elastomeric materials that are not subject to age control.

3.3.11 STORAGE - The engine system shall be designed to be stored, without degradation of reliability or operating life, for a period of 5 years when subjected to the following conditions.

3.3.11.1 STORAGE TEMPERATURE - The engine shall be designed to be capable of storage on the earth when exposed to an ambient temperature range of minus 30F to plus 140F at a relative humidity of 95 percent without degradation of reliability or operating life for a period of five years.

3.3.11.2 STORAGE ATTITUDE - The engine shall be designed not to suffer any detrimental effects during storage during which the engine attitude is maintained at no more than 7 degrees from the horizontal (forward end down); exceptions to this requirement shall be specified in this paragraph and be repairable by specified maintenance procedures.

3.3.11.3 STORAGE PREPARATION - The engine system shall be prepared for storage in accordance with the requirements of paragraph 3.3.1.1, Drawings.

3.3.11.3.1 OPERATIONAL CONTROL SYSTEM - The operational control system shall be designed to be stored with the fluid passages either completely or partially filled with hydraulic fluid in accordance with paragraph 3.2.1.2.1.5 Hydraulic Control Fluid.

4. QUALITY ASSURANCE - (TBD)

6. NOTES

6.1 SUPPLEMENTAL INFORMATION

6.1.1 DEFINITIONS - The definitions used in this specification and all Engineering Critical Component Specifications specified in paragraph 3.2.2.2 Engineering Critical Component List shall be as follows.

6.1.1.1 ALIGNMENT, DELIVERED THRUST VECTOR - The measured thrust vector angular displacement from the engine centerline and lateral displacement from the gimbal center in the XG ZG plane corresponding to the delivered engine aligned position as specified in the "Engine Log Book" for the individual delivered engine.

6.1.1.2 ALIGNMENT, MEASURED THRUST VECTOR - The thrust vector angular displacement from the engine centerline and lateral displacement from the gimbal center in the XG ZG plane with the engine in the basic engine aligned position, as measured during Contractor acceptance static testing of each delivered engine.

6.1.1.3 ASSEMBLY, GAS GENERATOR - The gas generator assembly consists of all components which form the gas generator control valve, gas generator injector, gas generator combustor body and all interconnecting components.

6.1.1.4 ASSEMBLY, THRUST CHAMBER - The thrust chamber assembly consists of all components which form the thrust chamber body, main injector, oxidizer dome and all interconnecting components.

6.1.1.5 ASSEMBLY, TURBOPUMP - The turbopump assembly consists of all components which form the oxidizer pump, fuel pump, turbine, lubricating system and all interconnecting components.

6.1.1.6 AXIS, X - A line in the plane formed by the intersection of the gimbal stage mounting surface keyway centerlines displaced 45° clockwise from the XG axis when looking aft.

6.1.1.7 AXIS, Y - The same as the engine centerline, with minus axis forward of the gimbal stage mounting surface.

6.1.1.8 AXIS, Z - A line in the plane formed by the intersection of the gimbal stage mounting surface keyway centerlines displaced 45° clockwise from the ZG axis when looking aft.

6.1.1.9 AXIS, XG - A line through the gimbal center parallel to the gimbal stage mounting surface keyway centerline in line with the engine number 2 actuator connect point, with the minus axis on the actuator side of the engine.

6.1.1.10 AXIS, ZG - A line through the gimbal center parallel to the gimbal stage mounting surface keyway centerline in line with the engine number 1 actuator connect point, with the minus axis on the actuator side of the engine.

6.1.1.11 CENTER, GIMBAL - The point about which the thrust chamber gimbals.

6.1.1.12 CENTERLINE, ENGINE - A line normal to the plane of and passing through the intersection of the gimbal stage mounting surface keyway centerlines.

6.1.1.13 CENTERLINE, THRUST CHAMBER - A line passing through the center of the injector face and the center of the thrust chamber 10:1 exit plane.

6.1.1.14 COCOON, THERMAL INSULATION - The thermal insulation cocoon is the engine envelope created by the thermal insulation applied to the outer periphery of the engine from the thrust chamber throat forward to the gimbal center.

6.1.1.15 DURATION, EFFECTIVE - Effective duration is the elapsed time between the attainment of a site thrust equal to 90 percent of rated thrust and engine cutoff signal.

6.1.1.16 ESTIMATE - A predicted characteristic which is considered the most probable representation of the real characteristic.

6.1.1.17 FACTOR, GIMBAL ADJUSTMENT - The distance and direction along a gimbal axis that a gimbal must be adjusted from the basic engine aligned position to provide the delivered thrust vector alignment. [Applicable to Task Assignment Engine 115-4 only.]

6.1.1.18 HEAD, NET POSITIVE SUCTION - The net positive suction head is the total pressure above fluid vapor pressure, reference to the plane of the pump flange face, expressed in feet of fluid.

6.1.1.19 HEAD, NET POSITIVE SUCTION, REQUIRED - The required net positive suction head is that minimum value at which a 2 percent loss of pump developed head occurs as a result of pump cavitation.

6.1.1.20 INSTABILITY, COMBUSTION - Combustion instability is uncontrolled pressure variations within the combustion chamber of sufficient magnitude to cause a dome mounted longitudinal accelerometer(s) output in excess of 141 g's peak.

6.1.1.21 LENGTH, REQUIRED ACTUATOR - The distance from an engine actuator connect point center to a location 75.000 inches

along the XG or ZG axis, respectively, and 10.500 inches along the Y axis from the gimbal center.

6.1.1.22 LIFE, SERVICE - The service life of the engine, in terms of total operating time and number of starts, will be that time and number, excluding secondary failure, routine repair, and adjustment of components or parts, that will not cause the engine to be subjected to major overhaul. A major overhaul is defined as any repair, servicing, disassembly, or replacement of a component which shall require recalibration or hot firing to demonstrate conformance of the engine with the model specification requirements and operation acceptability.

6.1.1.23 LOCATION, BASIC ENGINE CONNECT POINT - The location of a specific engine connect point relative to the engine X, Z and Y axes when the engine is in the basic engine aligned position.

6.1.1.24 LOCATION, DELIVERED ENGINE CONNECT POINT - The location of a specific engine connect point relative to the engine X, Z, and Y axes when the engine is in the delivered engine aligned position.

6.1.1.25 MASS, WET GIMBALED - The wet gimbaled mass is comprised of the complete mass of the wet engine less the mass of the non-gimbaled sections of the gimbal assembly.

6.1.1.26 POSITION, BASIC ENGINE ALIGNED - The engine position such that the engine centerline and the thrust chamber centerline are coincident.

6.1.1.27 POSITION, DELIVERED ENGINE ALIGNED - The thrust chamber centerline angular displacement from the engine centerline and lateral displacement from the gimbal center in the XG ZG plane corresponding to the delivered gimbal settings and required actuator lengths as specified in the "Engine Log Book" for the individual delivered engine.

6.1.1.28 PRESSURE, ATMOSPHERIC - The atmospheric pressure existing at the geometric altitude as reported in the US Standard Atmosphere, 1962: ICAO Standard Atmosphere to 20 KM, Proposed Extension to 32 KM, Tables and Data to 700 KM.

6.1.1.29 PRESSURE, DESIGN - The design pressure for a system or component is the pressure which results in critical loading when combined with all other loads imposed on a system or component. This pressure may be the maximum or minimum pressure resulting from start, operation and shutdown and will include the surges and oscillations resulting from start, operation and shutdown. In addition, the design pressure may, in some systems, be the maximum checkout pressure that results in critical loading of a component or system when Safe Operating Pressure criteria (personnel present) are applied.

6.1.1.30 PRESSURE, MAXIMUM CHECKOUT - The maximum checkout pressure is the maximum pressure to which a system may be subjected during leak and functional testing.

6.1.1.31 PRESSURE, NOZZLE STAGNATION - Nozzle stagnation pressure is the total absolute pressure at the thrust chamber throat. Based upon presently used combustion and fluid flow theories, the ratio of injector end chamber pressure to nozzle stagnation pressure for the F-1A engine is 1.146.

6.1.1.32 PRESSURE, PROOF - Proof pressure is the test pressure to which an item is subjected without deformation or permanent set that adversely affects engine operation.

6.1.1.33 SIGNAL, CUTOFF - Cutoff signal is an externally supplied electrical signal of sufficient magnitude and duration to actuate the engine closing control valve.

6.1.1.34 STABLE, DYNAMICALLY - Dynamic stability is the characteristic of an engine, following a self-triggered or forced thrust chamber pressure disturbance of predetermined magnitude, to attenuate the resulting oscillation below a predetermined level within a predetermined time period.

6.1.1.35 START, ENGINE - The attainment of a site thrust equal to 90 percent of rated thrust during engine starting.

6.1.1.36 TIME, DAMPING - When an engine is self-disturbed or deliberately disturbed by such means as the detonation of an explosive charge within the thrust chamber, the damping time of the resulting oscillations is the time in milliseconds between events (a) and (b) below:

a. The first peak chamber acceleration, as measured by a thrust chamber dome mounted longitudinal accelerometer, to exceed 141 g's peak.

b. The first peak chamber acceleration measurement, as measured by a thrust chamber dome mounted longitudinal accelerometer of magnitude less than plus or minus 56 g's, with subsequent oscillations remaining within plus or minus 56 g's for a minimum of 100 milliseconds thereafter.

6.1.1.37 VALUE, TIME AVERAGED - A value reduced to average mean square acceleration using a true rms voltmeter with a time constant of 0.833 seconds and an averaging time of 2.5 seconds minimum.

6.1.1.38 VECTOR, ACTUAL THRUST - The resultant force created by the burning propellants escaping from the engine thrust chamber.

Requirements on the actual thrust vector are demonstrated by requiring the sum of measurement error and the measured thrust vector alignment to comply with the requirements of the actual thrust vector.

6.1.1.39 WEIGHT, BURNOUT - The burnout weight is the engine wet weight less the weight of: (a) oxidizer downstream of the main valves, (b) fuel in the injector, and (c) one-half of the fuel in the forward thrust chamber manifold.

6.1.1.40 WEIGHT, DRY - The engine dry weight is the weight of all hardware in accordance with paragraphs 3.3.1.1, Drawings, with no fluids supplied to the engine.

6.1.1.41 WEIGHT, WET - The engine wet weight is the engine dry weight plus the weight of the fluids contained in the components and lines, filled to capacity.

6.1.1.42 STANDARD CONDITIONS, PRE-START STAGE FUEL PUMP INLET PROPELLANT - Pre-start stage fuel pump inlet propellant standard conditions are RP-1 fuel in accordance with MIL-R-25576C at a temperature of 60F and a density of 50.45 pounds per cubic foot, supplied to the pump inlet pre-start at a pressure of 45 psia (total).

6.1.1.43 STANDARD CONDITIONS, PRE-START STAGE OXIDIZER PUMP INLET PROPELLANT - Pre-start stage oxidizer pump inlet propellant standard conditions are liquid oxygen in accordance with MIL-P-25508C at a density of 71.38 pounds per cubic foot per the National Bureau of Standards Report USDC-9198, supplied to the pump inlet pre-start at a pressure of 80 psia (total).

6.1.1.44 GAS GENERATOR OXIDIZER THROTTLED ENGINE - An engine whose thrust level is controlled by adjusting the gas generator oxidizer system resistance such that a thrust related parameter is continually adjusted to a programed value. Turbine inlet temperature is allowed to vary.

6.1.1.45 CALIBRATED ORIFICED ENGINE - An engine whose thrust, mixture ratio, and turbine inlet temperature are established by acceptance testing and whose primary performance parameters vary with changes in propellant inlet conditions, ambient pressure, and whose internal environment (e.g. pressure, temperature) changes with variations in secondary performance characteristics (e.g. fluid resistance, expansion ratio).

6.1.1.46 UNCALIBRATED ORIFICED ENGINE - An engine whose thrust, mixture ratio, and turbine inlet temperature are not established by acceptance testing and whose primary performance parameters and internal environment (e.g. pressure, temperature) vary with changes in propellant inlet conditions, ambient pressure,

and variations in secondary performance characteristics (e.g. fluid resistance, expansion ratio).

6.1.1.47 SIDE - NUMBER 1 - The number one side of the engine is defined as that side of the engine where coordinates along the X axis are positive. (Figure A-3).

6.1.1.48 SIDE - NUMBER 2 - The number two side of the engine is defined as that side of the engine where coordinates along the X axis are negative. (Figure A-3)

6.1.1.49 TARGET THRUST - The target thrust is either the F-1A rated thrust (1800 kips) or the thrust level, between 1350 and 1800 kips, where a specific engine is rated.

6.1.2 SYMBOLS

| SYMBOL | PARAMETER | UNIT |
|---|---|---|
| At | Throat area | $in^2$ |
| C* | Characteristic velocity | ft/sec |
| C sub F | Thrust coefficient F/Pc At | No units |
| F | Thrust | lb |
| Isp | Specific impulse | sec |
| L* | Characteristic length Vc/At | in |
| Pc | Chamber pressure | psia |
| Q | Volumetric Fluid Flowrate | gpm |
| Vc | Combustion chamber volume | $in^3$ |
| W | Fluid flowrate | lb/sec |

6.1.3 ABBREVIATIONS

| | |
|---|---|
| ac | Alternating current |
| ATM | Atmospheres |
| dc | Direct current |
| EAU | Engine arming unit |
| ECU | Engine control unit |
| F | Degrees Fahrenheit |
| ft | Feet |
| ft/sec | Feet per second |
| GG | Gas generator |
| GN2 | Gaseous Nitrogen |
| g's | Ratio of acceleration to 32.2 $ft/sec^2$ |
| GSE | Ground Support Equipment |
| gpm | Gallons per minute |

| | |
|---|---|
| Hz | Hertz (cycles per second) |
| ICU | Ignition control unit |
| IMV | Ignition Monitor Valve |
| in | Inches |
| K | Degrees Kelvin |
| kip | One thousand pounds of force |
| lb | Pound |
| $lb/ft^3$ | Pounds per cubic foot |
| lb/sec | Pounds per second |
| LN2 | Liquid Nitrogen |
| MFV | Main fuel valve |
| MFVCV | Main fuel valve control valve |
| MLV | Main LOX VALVE |
| MOV | Main oxidizer valve |
| ppm | Parts per million |
| psia | Pounds per square inch absolute |
| rms | Root mean square |
| rpm | Revolutions per minute |
| sec | Seconds |
| SIU | Sequence Instrumentation Unit |

6.1.4 SUPPLEMENTAL INFORMATION ON THE OPERATIONAL CONTROL SYSTEM - Material in this paragraph is presented to describe the configuration and operation of the overall operational control system, sequence instrumentation unit, and the engine system start/stop sequence. This system as described meets the requirements of Section 3 Requirements.

6.1.4.1 OPERATIONAL CONTROL SYSTEM - The following is a description of the proposed operational control system components, a description of the operation of these components and the engine system sequencing requirements met by the operational control system. Operational control system component operational position and flow paths are presented in Drawing 101352. The five modes are Engine Ready-Checkout Mode, Checkout Sequence Complete Mode, Engine Armed Mode, Launch Commit Mode and Redundant Shutdown Mode. These stages or modes represent the Operational Control System and the positions of the control elements when the sequence of operations is completed.

OPERATIONAL CONTROL SYSTEM COMPONENT DESCRIPTIONS

a. Engine Control Unit - The Engine Control Unit contains two start solenoids, each with its slave pilot valve; two stop solenoids, each with its slave pilot valve; one hydraulic control valve with redundant actuation pistons for open and closed position; and a redundant gas generator closing control valve with redundant actuation pistons. Each start solenoid is independent of the other and is capable of initiating start of engine operation. Each stop solenoid is independent of the other and is capable of initiating stop of engine operation and actuating the redundant gas generator closing control valve to direct closing hydraulic pressure to the gas generator valve redundant closing port. A fluid circuit is provided which is used to indicate the closed position of the hydraulic control valve and the redundant gas generator closing control valve. Filters are provided for each solenoid valve and at the system open and closing supply ports.

b. Engine Arming Unit - The engine arming unit contains the igniter fuel control valve, the igniter fuel shutoff valve, the hypergol manifold, the hydraulic return control valve, the engine arming valve, and the hypergol cartridge follower. The engine arming valve is mechanically linked to the hypergol cartridge follower. The position of this valve is determined by the presence or absence of the hypergol cartridge. The igniter

fuel shutoff valve stops igniter fuel flow to the injector during engine shutdown and isolates the hydraulic return system from the hypergol container and thrust chamber injector during standby and checkout. The hydraulic return control valve incorporates a dash pot to delay return of the valve to the ground return position during engine shutdown to preclude high pressure from entering the ground return system. A fluid circuit is provided which is used to indicate the closed position of the engine arming and hydraulic return control valve.

The engine arming unit also contains the pressure switch checkout valve and the engine monitor valve. The pressure switch checkout valve and orificing in the test pressure sense line provides the capability for automatic remote checkout of the pressure switches. Bleed orifices are provided in the operational pressure sense line to the pressure switches which will allow adjustment of the sense pressure. This allows use of pressure switches with a single setting. The engine monitor valve is actuated by hydraulic pressure when the second main fuel valve is open allowing pressure indicating satisfactory engine performance to actuate the three pressure switches.

c. Ignition Control Unit - The ignition control unit contains the thrust chamber ignition monitor valve and the MFV control valve. The ignition monitor is a piston actuated poppet valve. The ignition monitor valve and MFV control valve test pistons and associated flow control orifices provide automatic checkout capability. A fluid circuit is provided which is used to indicate the closed position of the ignition monitor valve and the MFV control valve. The MFV control valve controls sequencing of the open and close hydraulic pressure to the main fuel valves. A closing delay is provided in the MFV control valve to delay closing of the main fuel valves during the shutdown sequence.

OPERATIONAL CONTROL SYSTEM FUNCTIONAL DESCRIPTION

a. Engine Ready-Checkout Mode - Ground hydraulic pressure and electric power (DC) are being supplied to the operational control system and all valves are in their closed positions. In

this condition the hypergol cartridge is not installed and the engine arming valve is in the checkout position. Hydraulic pressure from the hydraulic control valve (ECU) close port is applied to the closing sides of the main LOX valve and gas generator actuators and the MFV control valve (ICU). Ground supply pressure from upstream of the ECU is routed through the MFV control valve (ICU) to the closing sides of the main fuel valve actuators. Ground supply pressure is also routed to the igniter fuel control valve (EAU) and to the number 1 and 2 gimbal supply ports. A fluid monitoring circuit is provided in the operational control system to assure that all critical control elements are in the closed position prior to start of engine checkout. This series circuit originates in the ECU close port, passes through a land in the gas generator redundant closing control valve (ECU), the ignition monitor valve (ICU), the MFV control valve (ICU), the hydraulic return control valve (EAU), the engine arming valve (EAU), the pressure switch checkout valve (EAU), the engine monitor valve (EAU), and terminates at pressure switch number 1. If the pressure sensed by the switch is satisfactory for engine checkout, an electrical signal is sent across the engine interface to the facility indicating the operational control system is ready for checkout.

b. Checkout Sequence Complete Mode - Ground hydraulic pressure is being supplied to the operational control system. Operational system sequence checkout is initiated by the application of electrical power (DC) to the two start solenoids (ECU). Actuation of the start solenoids (ECU) vents high pressure from the spring cavities of the two slave pilot valves (ECU) allowing the pilot valves to open. This directs high pressure to the two actuating pistons for the hydraulic control valve actuating the hydraulic control valve to the opened position. When the hydraulic control valve actuates, the series monitoring circuit is interrupted and the signal from pressure switch number 1 is lost. High pressure from the hydraulic control valve (ECU) open port is routed to the ignition monitor valve in port (ICU) and to the number 2 main oxidizer valve open and sequence in ports.

NOTE: The passage connecting the open port to the sequence in port is internal to the main oxidizer valve.

As the number 2 main oxidizer valve opens, its sequence valve is mechanically opened allowing high pressure from the open port to be routed to the number 1 main oxidizer valve open and sequence in ports. The opening of number 1 main oxidizer valve results in opening of its sequence valve in a similar manner as number 2 main oxidizer valve. This allows high pressure to be routed to the gas generator oxidizer valve and sequence valve which operates allowing pressure to be routed to the igniter fuel control valve in port (EAU). High pressure at the igniter fuel control valve in port (EAU) causes it to actuate which also actuates the hydraulic return control valve (EAU). Hydraulic return flow is still directed to the ground return however, because the engine arming valve (EAU) is in the checkout position preventing hydraulic fluid from going to engine return. When the igniter fuel control valve (EAU) actuates the hydraulic fluid, which would be igniter fuel during engine operation, becomes a test pressure in the checkout mode. This test pressure is routed through the engine arming valve to the pressure switch checkout valve test port (EAU) and to the test port in the ICU. The test pressure in the EAU also serves to actuate the pressure switch checkout valve (EAU) allowing the test pressure to be routed through the two monitoring circuit passages in the EAU, through the engine monitor valve (EAU), and to the three pressure switches. Bleed orifices in the test pressure passage upstream of the pressure switch checkout valve are calibrated to provide a sense pressure below the minimum pickup pressure to the pressure switches. Lack of an electrical signal from the pressure switches is evidence that the lower limit of the switch pickup pressure range is satisfactory. Test pressure applied to the ICU is routed to the ignition monitor valve (ICU) and the MFV control valve (ICU). Bleed orifices in the test pressure passage to the ignition monitor valve test piston (ICU) are calibrated to provide a pressure at the acceptable actuating pressure limit. Actuation of the ignition monitor valve at this calibrated pressure value is evidence that the upper limit of the valve actuating range is satisfactory. When the

ignition monitor valve (ICU) is activated, high pressure from the ignition monitor valve in port (ICU) is is routed to the opening side of the gas generator fuel valve actuator. The gas generator fuel valve now opens. The test pressure that is checking the actuation pressure setting and actuating the ignition monitor valve is also checking the actuation pressure setting and actuating the MFV control valve in a similar manner. The passage to the MFV control valve is provided with a test piston that has a time delay feature which causes the MFV control valve to be actuated after the igniton monitor valve has actuated and the main fuel valves, which receive their opening pressure from the MFV control valve, are opened after the gas generator valve opens. In this manner the engine start sequence during operation can be closely duplicated during checkout.

When the MFV control valve actuates, pressure from the closing sides of the main fuel valve actuators is vented to return through the MFV control valve and high pressure is routed to number 2 main fuel valve open and sequence in ports.

NOTE: The passage connecting the open port to the sequence in port is internal to the main fuel valve.

As the number 2 main fuel valve opens, its sequence valve is mechanically opened allowing high pressure from the open port to be routed to the number 1 main fuel valve open and sequence in ports. The opening of number 1 main fuel valve results in opening of its sequence valve in a similar manner as number 2 main fuel valve. This allows high pressure to be routed to the engine monitor valve open port (EAU). Actuation of the engine monitor valve (EAU) allows test pressure to be routed to the pressure switches through the primary test passage (EAU). Bleed orifices in the test passage upstream of the engine monitor valve are calibrated to provide a sense pressure at the acceptable pickup pressure limit to the pressure switches. The receipt of 3 electrical signals from the 3 pressure switches is evidence that the upper limit of the switch pickup pressure is satisfactory. Actuation of the engine monitor valve is evidence of satisfactory start sequence complete. Valve

open timing during the start sequence is controlled by orifices internal to the operational control system.

c. Engine Armed Mode - Ground hydraulic pressure and electrical power (DC) are being supplied to the operational control system and all valves are in their closed position. In this condition the hypergol cartridge is installed and the engine arming valve is mechanically actuated and locked in the armed position. Hydraulic pressure from the hydraulic control valve (ECU) close port is applied to the closing sides of the main LOX valve, gas generator actuator and the MFV control valve (ICU). Ground supply pressure from upstream of the ECU is routed through the MFV control valve (ICU) to the closing sides of the main fuel valve actuators. Ground supply pressure is also routed to the igniter fuel control valve (EAU) and to the number 1 and 2 gimbal supply ports.

A fluid monitoring circuit is provided in the operational control system to assure that all critical control elements are in the closed position prior to start of engine operation. This series circuit originates in the ECU close port, passes through a land in the gas generator redundant closing control valve (ECU), the ignition monitor valve (ICU), the MFV control valve (ICU), the hydraulic return valve (EAU), the engine arming valve (EAU), the pressure switch checkout valve (EAU), the engine monitor valve (EAU), and terminates at pressure switches number 2 and 3. If the pressure sensed by the two pressure switches is satisfactory for engine start, two electrical signals (one from each pressure switch) are sent across the engine interface to the facility indicating the operational control system is ready for engine start.

d. Launch Commit Mode - In the launch mode condition, the engine has already been started and engine hydraulic pressure is being supplied to the operational control system from two supply lines. Each supply line taps fuel from the respective MFV. Prior to initiating engine start, the engine must be in the armed mode and sufficient ground supplied hydraulic pressure available, then operation can be initiated by the application of electrical power (DC) to the two start

solenoids (ECU). Actuation of the start solenoids (ECU) vents high pressure from the spring cavities of the two slave pilot valves (ECU) allowing the pilot valves to open. This directs high pressure to the two actuating pistons for the hydraulic control valve actuating the hydraulic control valve to the open position. When the hydraulic control valve actuates, the series monitoring circuit is interrupted and the signals (engine armed) from pressure switches number 2 and 3 are lost. High pressure from the hydraulic control valve (ECU) open port is routed to the ignition monitor valve in port (TCU) and to the number 2 main oxidizer valve open and sequence in ports.

NOTE: The passage connecting the open port to the sequence in port is internal to the main oxidizer valve.

As the number 2 main oxidizer valve opens, its sequence valve is mechanically opened allowing high pressure from the open port to be routed to the number 1 main oxidizer valve open and sequence in ports. Opening of the number 2 main oxidizer valve allows oxidizer propellant to flow to the thrust chamber. The opening of number 1 main oxidizer valve results in opening of its sequence valve in a similar manner as number 2 main oxidizer valve. This allows high pressure to be routed to the gas generator oxidizer valve and sequence valve which operates allowing pressure to be routed to the igniter fuel control valve in port (EAU). The opening of the gas generator oxidizer valve allows oxidizer propellant to flow to the combustor. High pressure at the igniter fuel control valve in port (EAU) causes it to actuate which also actuates the hydraulic return control valve (EAU). Hydraulic return flow is routed through the hydraulic return valve (EAU) to engine return. Actuation of the igniter fuel control valve allows high pressure hydraulic fluid to flow through the arming valve to the igniter fuel shutoff valve. The igniter fuel shutoff valve opens allowing the high pressure flow to pass to the gas generator hypergol cartridge diaphragm. The ground supplied hydraulic fluid ruptures the gas generator hypergol cartridge diaphragms and forces the hypergolic fluid ahead of it into the gas generator injector to establish ignition.

Upon priming of the gas generator igniter fuel system, the ground hydraulic supply then ruptures the main chamber hypergol cartridge diaphragm and establishes thrust chamber ignition. Satisfactory thrust chamber ignition is determined by the actuation of the ignition monitor valve (ICU). When the ignition monitor valve (ICU) actuates, high pressure from the ignition monitor valve in port (ICU) is routed to the opening side of the gas generator fuel valve actuator. The gas generator fuel valve opens allowing fuel to enter the combustor body, where after mixing with the oxidizer propellant it is ignited by either the previously signaled pyrotechnic igniters or by the previously established hypergolic ignition. Buildup of pressure in the combustor body drives the turbine to produce an increasing pump discharge pressure. During this period of the start sequence, closing pressure is maintained on both main fuel valves through the MFV control valve (ICU). When the fuel pump discharge pressure increases sufficiently, as sensed in the number 2 engine hydraulic supply line, to actuate the MFV control valve (ICU), pressure from the closing sides of the main fuel valve actuators is vented to return through the MFV control valve and high pressure is routed to number 2 main fuel valve open and sequence in ports.

NOTE: The passage connecting the open port to the sequence in port is internal to the main fuel valve.

As the number 2 main fuel valve opens, its sequence valve is mechanically opened allowing high pressure from the open port to be routed to the number 1 main fuel valve open and sequence in ports. Opening of number 2 main fuel valve allows fuel propellant to flow to the thrust chamber resulting in increasing chamber pressure. The opening of number 1 main fuel valve results in opening of its sequence valve in a similar as number 2 main fuel valve. This allows high pressure to be routed to the engine monitor valve port (EAU). Actuation of the engine monitor valve (sequence complete signal) allows a sense pressure from the igniter fuel system upstream of the igniter fuel shutoff valve to be routed to the three pressure switches. Receipt of electrical signals from the pressure switches is evidence of satisfactory engine performance

for launch commit. When fuel pump discharge pressure exceeds ground supply pressure at the operational system engine supply check valves (2), the engine takes over supply of operational system pressure.

e. Redundant Shutdown Mode (Operating) - Engine hydraulic pressure is being supplied to the operational control system from two supply lines. Each supply line taps fuel from the respective MFV. Application of electrical power (DC) to the two stop solenoids (ECU) vents high pressure from the spring cavities of the two slave pilot valves (ECU) allowing the pilot valves to open. This directs high pressure to the two actuating pistons for the hydraulic control valve and gas generator redundant closing control valve (ECU), actuating the hydraulic control valve to the closed position and the gas generator redundant closing control valve to the open position. High pressure from the hydraulic control valve (ECU) close port is routed to the closing sides of the MLV and GG valve actuators and the MFV control valve (ICU). High pressure from the gas generator redundant closing control valve is routed to the closing side of the GG valve redundant actuator.

The GG valve redundant closing system is completely independent of the primary shutdown system. The gas generator redundant shutdown control valve is controlled by the two stop solenoids through independent flow paths from the hydraulic control valve. The GG valve redundant actuator is sized to produce sufficient force when pressure is applied to close the gas generator valve, even under a malfunction condition where full open pressure is still applied to the open actuator.

During closing of the two main oxidizer and gas generator valves, the two main fuel valves are maintained in the open position by engine supply pressure taken upstream of the ECU and routed through the MFV control valve (ICU) to the opening sides of the main fuel valve actuators. Hydraulic pressure from the ECU close port, which was applied to MFV control valve close port when the hydraulic control valve was actuated, acts as a time delay actuator to close the MFV control valve. Closing of the MFV control valve vents high pressure from the opening side of the main

fuel valve actuators to return and routes high pressure to the closing side of the actuators.

NOTE: The delay in main fuel valve start to close is required to effect a smoother engine shutdown condition.

Venting of main fuel valve opening pressure allows the engine monitor valve to return to the closed position.

During the shutdown sequence, the igniter fuel control valve closes by spring force when system open pressure is vented by the hydraulic control valve stopping the flow of igniter fuel. The igniter fuel shutoff valve also closes by spring force to isolate the return system from the hypergol manifold. When the igniter fuel control valve starts to close, the hydraulic return control valve is able to start to close under spring force. However, the hydraulic timing device (bleeding of the cavity behind the piston) will control the return valve closing rate to prevent routing of return flow to ground return until the operational control system pressure has decayed to an acceptable level. This feature is required for end of flight shutdown when the ground return system is closed off.

Other elements in the system return to their standby position as follows:

1) The ignition monitor valve returns to the closed position by spring force as thrust chamber pressure decays.

2) The pressure switches deactuate when the engine monitor valve returns to the closed position as described previously.

3) The pressure switch checkout valve does not actuate during engine operation, therefore remains in the standby position during the shutdown.

4) The arming valve is mechanically locked by the expended hypergol cartridge, therefore it will remain in the armed position until the cartridge is removed.

After engine shutdown has been completed during a static test, removal of electrical power to

the stop solenoids and application of ground supplied hydraulic pressure will activate the hydraulic monitoring circuit and pressure switches number 2 and 3 will actuate and provide two electrical signals indicating that all critical control elements have returned to their closed position.

6.1.4.2 SEQUENCE INSTRUMENTATION UNIT - The following is a description of the Sequence Instrumentation Unit and a functional description of the operation as applied to the Operational Control System sequence monitoring requirements.

SEQUENCE INSTRUMENTATION UNIT COMPONENT DESCRIPTION

a. The sequence instrumentation unit is divided into two functionally related subsystems, the Start Sequence subsystem and the Stop Sequence subsystem. Each of these subsystems contain spring loaded pistons/pushrods that can be incrementally operated by a pressure source. An electrical transducer is used to monitor the position of the pushrods that are incremented by the signal pressures. During the start sequence it is desirable that the step changes (electrical transducer output) are all increases and during the stop sequence that all steps are decreases. Pressure signals available to the SIU are not in all cases a pressure source as required to provide increasing steps during start or in the case of shutdown a loss of pressure to provide decreasing stops. In these cases where the signal is not of the desired type, valving is provided to change either sources to vents or vents to sources. Prior to start, after sequence complete and after shutdown all piston/pushrods are in the same position and the electrical transducer output is the same.

SEQUENCE INSTRUMENTATION UNIT FUNCTIONAL DESCRIPTION

a. Prior to initiation of the start sequence, hydraulic pressure must be supplied to the Operational Control System. When all necessary determinations of engine readiness (such as engine armed, or engine ready-checkout mode) have been completed, an engine start signal can be provided to the Engine Control Unit. This signal type and source, as are all following signals, is tabulated in paragraph 3.1.1.2.5, Operational Control System. The sequence of operation of the operation control system is

described in paragraph 6.1.4.1, Operational Control System. No further reference to this sequence or the method of attaining the operational control system signals will be made in this description of the SIU operation.

At this time supply pressure is applied to P1, P13, P14, P15, P16 and PS. Return pressure is applied to P0, P2, P3, P4, P5, P6-12, P7, P8, P9, P10, P11, and PR. Output of the electrical transducer shall be maximum (approximately 5 volts DC).

When Signals P1 (pressure off) and P0 pressure on are supplied the start sequence piston/pushrods are positioned such that the output of the electrical transducer is minimum (approximately zero volts DC). When signal P2 (pressure on) is supplied the piston/pushrod is incremented and the electrical output is approximately 14 percent of full scale. When signal P3 (pressure on) is supplied the piston/pushrod is again incremented and the electrical output increases to approximately 25 percent of full scale. In a like manner signal P4 comes on electrical output of approximately 36 percent of full scale. Signals P5 and P11 (pressure off) is applied and operates a valve to condition the signal allowing the piston/pushrod to increment and the electrical output signal to increase to approximately 57 percent of full scale. In a like manner P6 and P7 provide additional steps to 67 and 80 percent of full scale. When P8 (pressure on) is applied. The last step is accomplished and the electrical output is at full scale (approximately 5 volts).

b. At the initiation of the Stop Signal (electrically staggered for checkout) an electrical signal is sent to the No. 1 stop solenoid. Signal P9 (pressure on) is applied causing valving to operate, venting the overriding pressure to the piston/pushrod and incrementing the output of the electrical transducer to approximately 80 percent of full scale. When P10 (pressure on) is applied, the signal is conditioned by valving to operate the piston/pushrod and increment the electrical Transducer output to approximately 67% of full scale. Signal P11 (pressure off) is applied and operates the piston/pushrod to increment the electrical Transducer output to be incremented to 57% of full scale. Signals

P12, 13, 14, 15, and 16 (pressure off) are applied and in a like manner increment the electrical transducer output to approximately 50%, 36%, 25%, 14% and 0% of full scale respectively.

These events (P1 through P16 and the application of the electrical signals), when analyzed with respect to time, provide sequential verification of the operational control system.

10. APPENDIX

10.1 STAGE/FACILITY SUPPLIED INSTRUMENTATION - The stage shall provide instrumentation listed in Table 10-1 to be used in conjunction with Flight Instrumentation in accordance with paragraph 3.1.1.2.8.1 Flight Instrumentation and Stage Static/Acceptance Test Instrumentation in accordance with paragraph 3.1.1.2.8.2 Stage Static/Acceptance Test instrumentation for stage static test.

TABLE 10-1
STAGE/FACILITY SUPPLIED INSTRUMENTATION

| Parameter Name | Source/ Precision | Frequency Response | Range |
|---|---|---|---|
| LOX Pump Inlet Pressure (inboard) | TBD | TBD | 0-500 psia |
| LOX Pump Inlet Pressure (outboard) | TBD | TBD | 0-500 psia |
| Fuel Pump Inlet Pressure (inboard) | TBD | TBD | 0-300 psia |
| Fuel Pump Inlet Pressure (outboard) | TBD | TBD | 0-300 psia |
| LOX Pump Inlet Temperature (outboard) | TBD | TBD | -270 to -300F |
| Fuel Pump Inlet Temperature (outboard) | TBD | TBD | -40 to +140F |

10.2 TASK ASSIGNMENT ENGINE 115-4 - Task assignment engines 115-4 will not comply with all requirements of this specification. Deviations to the requirements of this specification for Task Assignment Engine 115-4 are specified in this section. The format for this Section will be identical to the overall specification with only those paragraphs where deviation are required identified and only the deviation for Task Assignment Engine 115-4 provided.

. . . . . .

Section 1. No Deviations

Section 2. No Deviations

Section 3. Requirements

3.1.1.1 PRIMARY PERFORMANCE CHARACTERISTICS

3.1.1.1.3 STARTING - Figure A-1a.

3.1.1.1.4 SHUTDOWN - Figure A-2a.

3.1.1.1.5 WEIGHT PROPERTIES - The engine and accessories shall be designed with the following weights as goals:

a. Dry Weight - The dry weight[1] of the engine and accessories shall not exceed 18,750 pounds.

b. Wet Weight - The wet weight[1] of the engine and accessories shall not exceed 20,950 pounds.

c. Burnout Weight - The burnout weight[1] of the engine and accessories shall not exceed 20,530 pounds.

3.1.1.1.6 GIMBAL PROPERTIES - The engine shall be designed with the following gimbaling capability mass characteristics, and restraints for the engine and accessories as goals:

a. No deviation

b. No deviation

c. The wet gimbaled mass[1] characteristics are as follows.

1. Moment of Inertia about Engine Axis Iy = 8,600 slug ft squared.

2. Moment of Inertia about Engine axis Ix = 32,250 slug ft squared.

3. Moment of Inertia about Engine axis Iz = 29,000 slug ft squared.

4. Center of Gravity

y = +52.1 inches

x = 0.4 inches
z = +16.7 inches

5. Weight - 20,750 pounds

d. No deviation

3.1.1.2 SECONDARY PERFORMANCE CHARACTERISTICS

3.1.1.2.1 THRUST SYSTEM

3.1.1.2.1.1 FLUIDS HANDLED - The thrust system shall utilize liquid oxygen and RP-1 as propellants for operation. Liquid Oxygen and RP-1/RJ-1 shall be used, with hypergolic fluid to provide an ignition source, to establish thrust chamber ignition. Ethylene glycol shall be used as a thrust chamber prefill during starting. Turbine exhaust products shall be injected into the thrust system. The thrust system shall also be compatible with Trichloroethylene, gaseous nitrogen, and water.

3.1.1.2.2 FUEL FEED SYSTEM

3.1.1.2.2.1 FLUIDS HANDLED - The fuel feed system shall accept vehicle/facility supplied RP-1 for starting and operation. The system shall also be compatible with RJ-1, Trichloroethylene, water, ethylene glycol, and gaseous nitrogen.

3.1.1.2.3 OXIDIZER FEED SYSTEM - No Deviations

3.1.1.2.4 TURBINE DRIVE AND EXHAUST SYSTEM

3.1.1.2.4.9 FLOW CONTROL ORIFICING

1. Gas Generator fuel feed system orifice located at the interface between the throttle valve outlet and the gas generator fuel feed line. Provisions shall also be made at the interface between the fuel feed line and the shutoff valve.

3.1.1.2.5 OPERATIONAL CONTROL SYSTEM

3.1.1.2.5.5 POWER INPUTS

h. ELECTRICAL - The operational control system shall receive redudant electrical signals within the range of 20 to 36 vdc, TBD volts to initiate the engine start sequence. The duration of these signals shall be more than 0.10 seconds and less than 180 seconds.

i. ELECTRICAL - The operational control system shall receive redundant electrical signals within the range of 20 to 36 vdc, TBD volts, to initiate the engine stop sequence. The duration of these signals shall be more than 0.10 seconds and less than 180 seconds.

3.1.1.2.5.11 ORIFICING - The operational control system shall be designed to allow orificing of control system hydraulic fluid passages. The function and location of these orifice provisions are specified in Table G-2. Type A and Type B orifices are both variable orifices.

3.1.1.2.6 IGNITION SYSTEM - The function of the ignition system shall be to provide an ignition source for the propellants in the Thrust System, paragraph 3.1.1.2.1 and the Turbine Drive and Exhaust System, paragraph 3.1.1.2.4. The system shall also provide fuel to sustain ignition. The primary components of the thrust chamber ignition system are the igniter fuel flow control valving, hypergol supply, interconnect ducting, and the gas generator injector. The engine shall also have the capability to utilize pyrotechnic igniters and associated electrical harnesses. The detailed quantitative characteristics for the thrust chamber ignition system are tabulated in Table H-1. The detailed quantitative characteristics for the gas generator ignition system are tabulated in Table (TBD).

3.1.1.2.6.4 POWER INPUTS - The ignition system shall be provided the following power inputs.

a. MECHANICAL - No Deviation

b. MECHANICAL - No Deviation

c. ELECTRICAL - The engine shall also have the capability of being provided electrical power for the pyrotechnic igniters used to establish ignition in the gas generator. TBD watts at TBD volts shall be supplied meeting the sequence requirements of the operational control system.

3.1.1.2.6.5 POWER OUTPUTS - The ignition system shall generate the following outputs.

a. MECHANICAL - No deviation.

b. ELECTRICAL - The ignition system shall provide an electrical indication of installation of the pyrotechnic igniters. This indication shall assure that each of the two igniters is installed.

c. ELECTRICAL - The ignition system shall provide an electrical indication of the satisfactory burning of the pyrotechnic igniters. Detection of satisfactory burning of either of the two igniters or both of the igniters will fulfill this requirement.

3.1.1.2.6.10 REDUNDANCY REQUIREMENTS - The system shall provide redundant ignition sources to each thrust chamber injector compartment and to the gas generator combustor. The engine will also have the capability to utilize redundant (two) pyrotechnic igniters for the gas generator.

3.1.1.2.7 THRUST CONTROL SYSTEM - No Deviations

3.1.1.2.8 INSTRUMENTATION SYSTEMS

3.1.2.8.3 SPECIAL TEST INSTRUMENTATION - The engine system shall be designed to provide porting, transducer mounting, and plumbing to instrument the parameters listed in Table K-3a.

3.1.1.2.8.3.1 SPECIAL TEST INSTRUMENTATION PORTS - The engine system shall be designed to provide special test instrumentation porting conforming to RP260-1001 for pressure and temperature instrumentation and to TBD for vibration instrumentation.

3.1.1.2.9 VEHICLE/STAGE SERVICE SYSTEM - No Deviations

3.1.2 OPERABILITY

3.1.2.7.2.3 COMBUSTION CHAMBER PURGE - The engine shall utilize gaseous combustion chamber purges (Thrust Chamber and Gas Generator).

3.1.2.7.2.17 LOWERED PREFILL - The engine shall be capable of starting safely after the thrust chamber prefill fluid has been lowered due to gimbal checkouts not to exceed the requirements of paragraph 3.1.1.1.6 Gimbal Properties.

3.2 ENGINE DEFINITION

3.2.1.2.1.1 NITROGEN - Nitrogen in accordance with MIL-P-27401B; Propellant Pressurizing Agent. Nitrogen, shall be supplied to the engine for servicing purges.

The Nitrogen shall be supplied from loading systems equipped with nominal 40 micron or finer filters. These filters shall have a maximum pore size of 100 microns as determined by bubble-point and/or glass bead testing. Operational purge fluid temperature, pressure and flow rate nomiral valves and limits plus sequencing requirements shall be in accordance with R-6749, F-1 Engine Interface Document.

3.2.1.2.1.4 HYPERGOL FLUID - Hypergol fluid in accordance with R-6749, F-1 Engine Interface Document, shall be provided for thrust chamber and gas generator ignition. The engine shall also have the capability to utilize pyrotechnic igniters for gas generator ignition.

3.2.1.2.1.6 THRUST CHAMBER PREFILL FLUID - The engine shall utilize ethylene glycol in accordance with R-6749, F-1 Engine Interface Document for thrust chamber prefill. This prefill shall be provided from a ground source for engine starting.

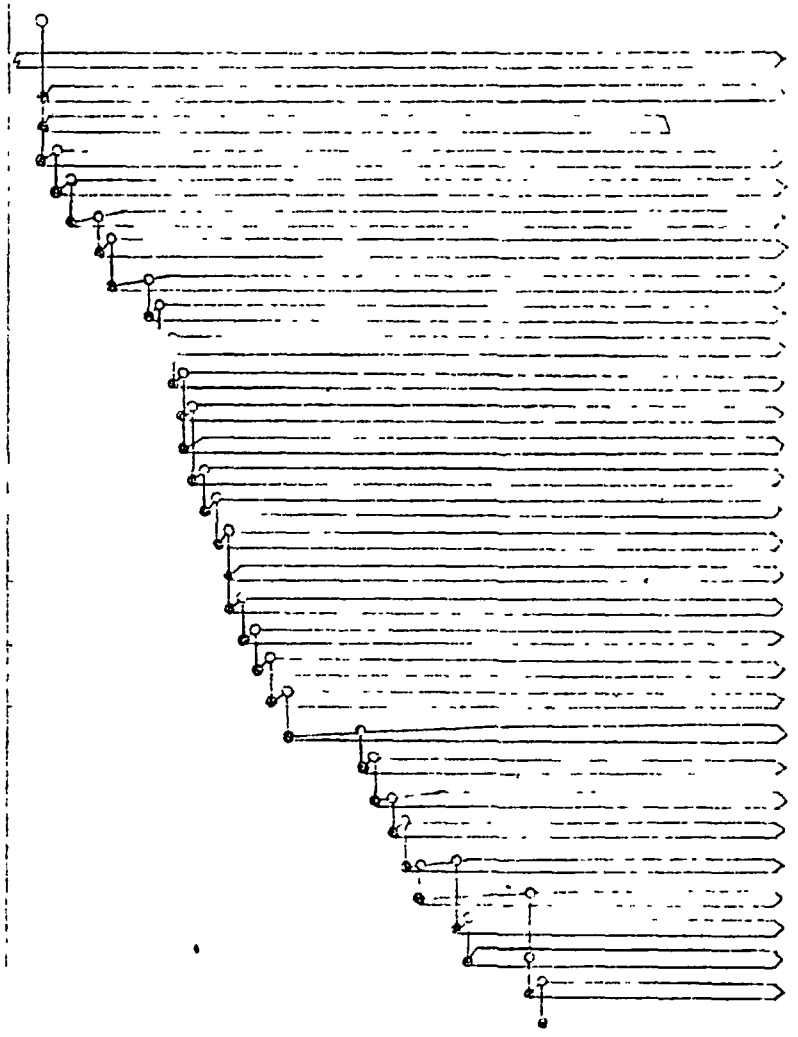
3.2.1.2.3.6 LOX DOME & GG INJECTOR PURGE - The engine shall interface at the LOX Dome and gas generator LOX injector purge line in accordance with (TBD). Nitrogen in accordance with paragraph 3.2.1.2.1.1 Nitrogen shall flow to the engine through this interface.

3.2.1.2.3.7 TURBOPUMP SEAL CAVITY PURGE - The engine shall interface at the seal cavity purge line in accordance with (TBD). Nitrogen in accordance with paragraph 3.2.1.2.1.1 Nitrogen shall flow through this interface.

3.2.1.2.3.8 THRUST CHAMBER JACKET PREFILL - The engine shall interface at the thrust chamber jacket prefill line in accordance with (TBD). Ethylene Glycol in accordance with paragraph 3.2.1.2.1.6 Thrust Chamber Prefill Fluid shall flow to the engine through this interface.

3.3.10.5 SYNTHETIC RUBBER PARTS - Does Not Apply.

1. Start Signal (Manual)
2. Turbopump Intermediate Seal Purge Energized
3. LOX Dome Operational Purge Energized
4. Ignition Stage Timer Energized
5. Engine Control Unit Open Signal
6. Engine Control Unit In Open Position
7. No. 2 Main Oxidizer Valve Open
8. No. 2 Oxidizer Sequence Valve Open
9. No. 1 Main Oxidizer Valve Open
10. No. 1 Oxidizer Sequence Valve Open
11. Gas Generator LOX Valve Open
12. Gas Generator Sequence Valve Open
13. Igniter Fuel Control Valve Open
14. Hydraulic Return Control Valve (Engine)
15. Igniter Fuel Shutoff Valve Open
16. GG Hypergol Cartridge Rupture
17. GG Ignition System Prime
18. GG Combustor Ignition
19. Thrust Chamber Hypergol Cartridge Rupture
20. Thrust Chamber Ignition
21. Ignition Monitor Valve Actuates
22. GG Fuel Valve Open
23. Turbopump Speed Increases
24. MFV Control Valve Actuates
25. No. 2 Main Fuel Valve Open
26. No. 2 Fuel Sequence Valve Open
27. No. 1 Main Fuel Valve Open
28. Main Thrust Increase
29. No. 1 Fuel Sequence Valve Open
30. Engine Monitor Valve Actuates
31. Pressure Switches Actuate
32. Start Sequence Complete/Launch Commit



LEGEND

- Initiating Event
- Resulting Event
- Valve, Solenoid or Relay Movement

* Task Assignment Engine 115-4

FIGURE A-1a

ENGINE START SEQUENCE

(HYPERGOL GG IGNITION)



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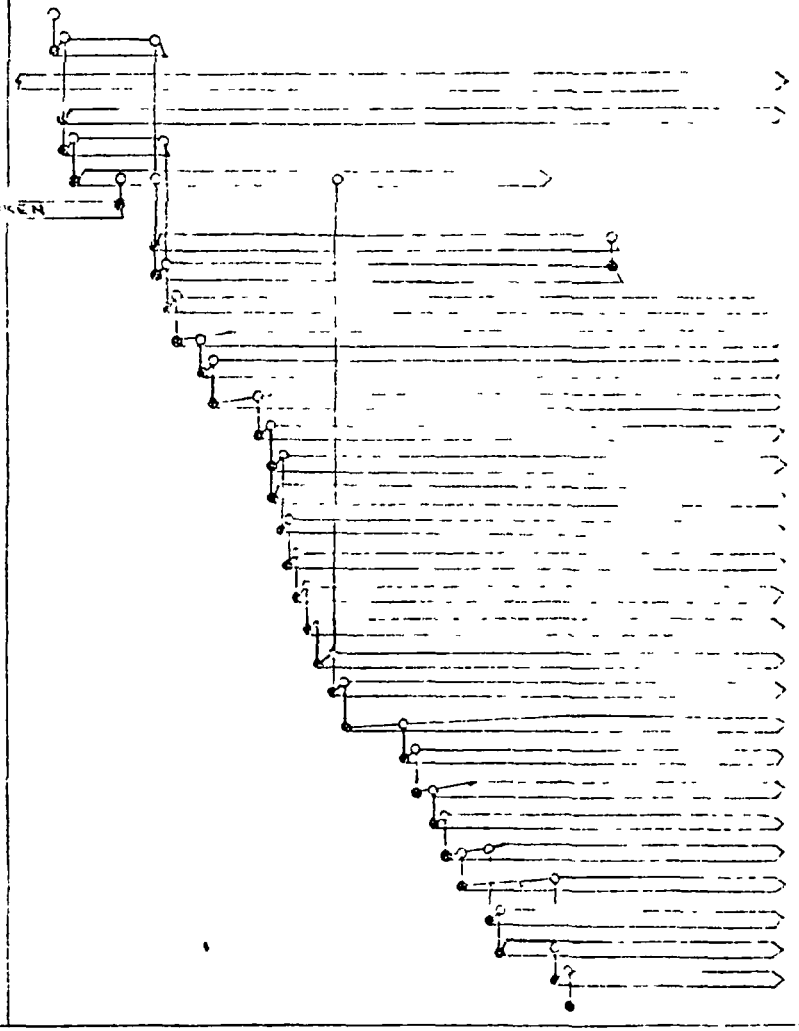
1. Start Signal (Manual)
2. Start Delay Timer Energized
3. Turbopump Intermediate Seal Purge Energized
4. LOX Dome Operational Purge Energized
5. GG Igniter Squib Power On
6. GG Igniters Firing
7. GG Igniter Link Continuity
8. Ignition Stage Timer Energized
9. Engine Control Unit Open Signal
10. Engine Control Unit In Open Position
11. No. 2 Main Oxidizer Valve Open
12. No. 2 Oxidizer Sequence Valve Open
13. No. 1 Main Oxidizer Valve Open
14. No. 1 Oxidizer Sequence Valve Open
15. Igniter Fuel Control Valve Open
16. Hydraulic Return Control Valve (Engine)
17. Igniter Fuel Shutoff Valve Open
18. Hypergol Cartridge Rupture
19. Thrust Chamber Ignition
20. Ignition Monitor Valve Actuates
21. GG Ball Valve Open
22. GG Propellant Ignition
23. Turbopump Speed Increase
24. MFV Control Valve Actuates
25. No. 2 Main Fuel Valve Open
26. No. 2 Fuel Sequence Valve Open
27. No. 1 Main Fuel Valve Open
28. Main Thrust Increase
29. No. 1 Fuel Sequence Valve Open
30. Engine Monitor Valve Actuates
31. Pressure Switches Actuate
32. Start Sequence Complete/Launch Commit




* Task Assignment Engine 115-4

LEGEND
- Initiating Event
- Resulting Event
- Valve, Solenoid or Relay Movement

ENGINE START SEQUENCE

FIGURE A-1a (Cont'd)

(PYROTECHNIC GG IGNITION)

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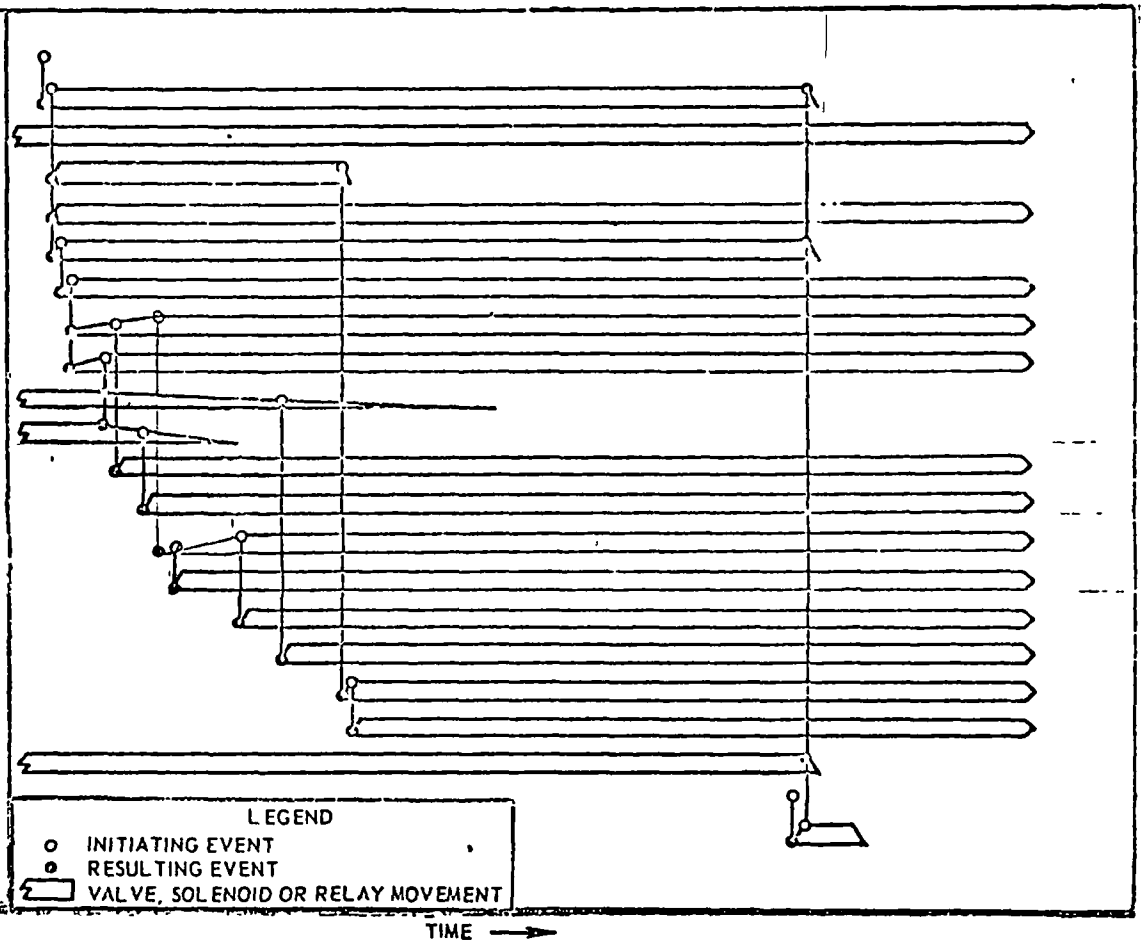
1. CUTOFF SIGNAL
2. CUTOFF RELAY ENERGIZED
*3 TURBOPUMP INTERMEDIATE SEAL PURGE ENERGIZED
*4 GROUND HYDRAULIC SUPPLY TIMER ENERGIZED
*5 LOX DOME SERVICE PURGE ENERGIZED
6 ENGINE CONTROL UNIT CLOSED SIGNAL
7. ENGINE CONTROL UNIT IN CLOSED POSITION
8. OXIDIZER VALVES CLOSE
9. GG BALL VALVE CLOSE
10 TURBOPUMP SPEED DECREASES
11 START OF THRUST DECREASE
12 OXIDIZER SEQUENCE VALVES CLOSE
13 ENGINE MONITOR UNIT CLOSE
14 FUEL VALVES CLOSE
15. SECOND FUEL SEQUENCE VALVE CLOSE
16. FIRST FUEL SEQUENCE VALVE CLOSE
17. IGNITER FUEL VALVE CLOSE
18 GROUND HYDRAULIC SUPPLY VALVE OPEN
19 HYDRAULIC RETURN VALVE TO GROUND POSITION
*20 LOX DOME OPERATIONAL PURGE ENERGIZED
21. RESET SIGNAL (MANUAL)
22. RESET RELAY ENERGIZED




* Task Assignment Engine 115-4

ENGINE STOP

Figure A-2a

TABLE K-3a

SPECIAL TEST INSTRUMENTATION

PRESSURES

| PARAMETER | BOSS LOCATION | PLUMBING REQUIREMENTS | | |
|---|---|---|---|---|
| | | PLUMB TO PANEL | ENGINE MOUNTED TRANSDUCERS | PLUG PORT |
| Fuel Pump Discharge No. 1 | No. 1 Fuel Duct | X | | |
| Fuel Pump Discharge No. 2 | No. 2 Fuel Duct | | | X |
| LOX Pump Discharge No. 1 | No. 1 LOX Duct | X | | |
| LOX Pump Discharge No. 2 | No. 2 LOX Duct | | | X |
| GG Fuel Scoop Outlet Pressure | GG Fuel Duct | X | | |
| GG LOX Throttle Valve Inlet | GG LOX Throttle Valve | X | | |
| GG LOX Throttle Valve Outlet | GG LOX Duct | X | | |
| GG Fuel Valve Inlet | GG Fuel Duct | X | | |
| GG LOX Valve Inlet | GG LOX Duct | X | | |
| GG Fuel Injection | GG Injector | | X | |
| GG Fuel Injection | GG Injector | | | X |
| GG LOX Injection | GG Injector | | X | |
| GG Chamber Pressure | GG Combustor | | X | |
| GG Chamber Pressure | GG Combustor | | X | |
| Turbine Inlet | GG Combustor | X | | |
| Exhaust Flow Straightener Inlet | Turbopump | | X | |
| LOX Dome Inlet No. 2 | LOX Dome | X | | |
| LOX Injection | LOX Dome | X | | |
| LOX Injection | LOX Dome | | | X |
| No. 1 Common Hydraulic Supply | Seal Plate between Gimbal Actuator Supply Manifold and #1 Mounting Base | X | | |

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## TABLE K-3a

### SPECIAL TEST INSTRUMENTATION (Cont'd)

### PRESSURES

| PARAMETER | BOSS LOCATION | PLUMBING REQUIREMENTS | | |
|---|---|---|---|---|
| | | PLUMB TO PANEL | ENGINE MOUNTED TRANSDUCERS | PLUG PORT |
| Igniter Fuel Control Valve Supply | Seal Plate between Manifold & #1 Mounting Base | | | X |
| Arming Valve Igniter Fuel Supply | Engine Arming Unit | | | X |
| Ground Hydraulic Return | Seal Plate Between Engine Arming Unit and #1 Mounting Base | X | | |
| Engine Hydraulic Return | Seal Plate Between Engine Arming Unit and #1 Mounting Base | X | | |
| Pressure Switch Checkout Valve Test Inlet | Corresponding Passage in Engine Arming Unit | X | | |
| Pressure Switch Checkout Valve Thrust OK | Corresponding Passage in Engine Arming Unit | X | | |
| No. 1 Pressure Switch Supply | Seal Plate Between Engine Arming Unit and #1 Mounting Base | X | | |
| No's. 2 & 3 Pressure Switch Supply | Seal Plate Between Engine Arming Unit and #1 Mounting Base | X | | |
| No. 1 Gimbal Return | #1 Gimbal Actuator Supply Manifold | | | X |
| No. 2 Gimbal Return | #2 Gimbal Actuator Supply Manifold | | | X |
| No. 2 Common Hydraulic Supply | Seal Plate Between Gimbal Actuator Supply Manifold and #2 Mounting Base | | | X |
| Ignition Monitor Valve Test Cavity | Ignition Control Unit | | | X |
| Main Fuel Valve Control Valve Cavity | Ignition Control Unit | | | X |



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SPECIAL TEST INSTRUMENTATION (Cont'd)

PRESSURES

| PARAMETER | BOSS LOCATION | PLUMBING REQUIREMENTS | | |
|---|---|---|---|---|
| | | PLUMB TO PANEL | ENGINE MOUNTED TRANSDUCERS | PLUG PORT |
| Main Oxidizer Valve Actuator Open Cavity | Main Oxidizer Valve | | | X |
| Main Oxidizer Valve Actuator Close Cavity | Main Oxidizer Valve | | | X |
| Main Oxidizer Valve Sequence Out Port | Main Oxidizer Valve | | | X |
| Main Oxidizer Valve Poppet Cavity | Main Oxidizer Valve | | | X |
| Main Fuel Valve Actuator Open Cavity | Main Oxidizer Valve | | | X |
| Main Fuel Valve Actuator Close Cavity | Main Fuel Valve | | | X |
| Main Fuel Valve Sequence Out Port | Main Fuel Valve | | | X |
| Main Fuel Valve Poppet Cavity | Main Fuel Valve | | | X |
| Main Fuel Valve Outlet | Main Fuel Valve | | | X |
| Gas Generator Valve Oxidizer Actuator Open Cavity | Gas Generator Valve | | | X |
| T/C Igniter Supply Cavity | Engine Arming Unit | | X | |
| GG Igniter Supply Cavity | Engine Arming Unit | | X | |
| Gas Generator Valve Actuator Redundant Close Cavity | Gas Generator | | | X |
| Fuel Manifold | Thrust Chamber | X | | |
| Fuel Injection | Thrust Chamber | X | | |

TABLE K-3a

SPECIAL TEST INSTRUMENTATION (Cont'd)

PRESSURES

| PARAMETER | BOSS LOCATION | PLUMBING REQUIREMENTS | | |
|---|---|---|---|---|
| | | PLUMB TO PANEL | ENGINE MOUNTED TRANSDUCERS | PLUG PORT |
| Fuel Injection | Thrust Chamber | | | X |
| Combustion Chamber | Thrust Chamber | | X | |
| LOX Pump Seal Cavity | Turbopump | X | | |
| Fuel Pump Impeller Backcasing | Turbopump | X | | |
| First Stage Wheel In | Turbopump | X | | |
| Thrust Bearing Lube Supply | Turbopump | X | | |
| Gas Generator Valve Fuel Actuator Open Cavity | Gas Generator Valve | | | X |
| Gas Generator Valve Fuel Actuator Close Cavity | Gas Generator Valve | | | X |



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TABLE K-3-3

SPECIAL TEST INSTRUMENTATION (CONT'D)

TEMPERATURES

| PARAMETER | BOSS LOCATION | PLUMBING REQUIREMENTS | | |
|---|---|---|---|---|
| | | PLUMB TO PANEL | ENGINE MOUNTED TRANSDUCERS | PLUG PORT |
| Turbine Inlet | Gas Generator | | | X |
| Turbine Inlet Manifold | Turbopump | | | X |
| No. 2 Bearing | Turbopump | | X | |
| No. 3 Bearing | Turbopump | | X | |
| Turbine Exhaust | Exhaust Duct | | | X |



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TABLE K-3a

SPECIAL TEST INSTRUMENTATION (Cont'd)

ACCELERATION

| PARAMETER | BOSS LOCATION | PLUMB TO PANEL | ENGINE MOUNTED TRANSDUCERS | PLUG PORT |
|---|---|---|---|---|
| VSC No. 1 | LOX Dome Outer Bolt Hole Circle | | | X |
| VSC No. 2 | LOX Dome Outer Bolt Hole Circle | | | X |
| LOX Dome Pos. I | LOX Dome Outer Bolt Hole Circle | | | X |
| Gas Generator Combustor (X) | Gas Generator Combustor | | | X |
| Gas Generator Combustor (Y) | Gas Generator Combustor | | | X |
| Gas Generator Combustor (Z) | Gas Generator Combustor | | | X |
| Fuel Pump Housing (X) | Fuel Pump Housing | | | X |
| Fuel Pump Housing (Y) | Fuel Pump Housing | | | X |
| Fuel Pump Housing (Z) | Fuel Pump Housing | | | X |
| LOX Pump Inlet Flange (Y) | LOX Pump Inlet Housing | | | X |
| Turbine Exhaust Inlet (X) | Exhaust Flow Straightener Inlet Flange | | | X |
| Turbine Exhaust Inlet (Y) | Exhaust Flow Straightener Inlet Flange | | | X |
| Turbine Exhaust Inlet (Z) | Exhaust Flow Straightener Inlet Flange | | | X |



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